Lake Michigan – Muskegon Lake Connectivity Workshop

Report for Workshop I

April 28 – 29, 2014
Annis Water Resources Institute, Grand Valley State University
Muskegon, MI

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GRAND VALLEY STATE UNIVERSITY ROBERT B. ANNIS WATER RESOURCES INSTITUTE

GLERL Great Lakes Environmental Research Laboratory

Executive Summary

The Lake Michigan-Muskegon Lake Connectivity workshops are a series of three workshops designed to develop a collaborative and coordinated long-term research program that links the watershed, Muskegon River, Muskegon Lake, and nearshore/offshore Lake Michigan (MUSkegon Interconnected eCosystem, MUSIC). Emphasis is on an integrated and interdisciplinary approach that includes hydrodynamics and hydrology, chemistry, biology and ecology, and socioeconomics across the MUSIC. The workshops are designed to bring together researchers, resource managers, and stakeholders to construct a framework with an overall goal to understand and predict the role of environmental stressors on ecosystem services, human health, and societal needs. The end product will be an Implementation Plan to guide this effort.

The first workshop, reported here, brought together governmental and academic researchers to inform one another about ongoing research, identify scientific needs, and begin the dialog for developing a long-term research program. The second workshop will bring together resource managers and stakeholders toward the general goals of information exchange, identifying management and public needs, and engaging participants in the process. The last workshop will provide a forum for discussion and for providing final comments. Following these workshops, a writing team will be established to draft the Implementation Plan.

This report summarizes the results of the first workshop, which was held on April 28-29, 2014 at the Annis Water Resources Institute Grand Valley State University (AWRI-GVSU) in Muskegon, MI. The workshop was organized and convened by NOAA Great Lakes Environmental Research Laboratory (GLERL) and AWRI-GVSU. Presentations of research were organized into 4 sessions: food web and fisheries; water quality and wetlands; hydrology, hydrodynamics, observing systems and remote sensing; and integrated assessment. Open discussion followed each session. There were also presentations on the NOAA Habitat Blueprint and the habitat restoration completed in Muskegon Lake. Muskegon Lake has recently been designated by NOAA as a Habitat Blueprint site. Discussion notes are provided following each session in the agenda, found in this report. All presentations are included in the appendix. Some key points from the workshop were:

- The generality of the MUSIC as a dynamic estuarine zone of intense productivity and biogeochemical cycling, lends itself as a test model for similar efforts in coastal zones elsewhere that are facing anthropogenic and climate change-driven stress.
- There is a rich history of long-term monitoring and research within MUSIC.
- Muskegon Lake is an Area of Concern (AOC) and represents a microcosm of Great Lakes restoration.
- Examples of some of the knowledge gaps and needs included: development of a hydrodynamic model (biophysical model) for Muskegon Lake that is coupled with the river and Lake Michigan, impact of Muskegon Lake plume on Lake Michigan, high frequency and event response sampling, role of satellite remote sensing, need to expand work that occurs in Lake Michigan to Muskegon Lake.
- Identified a strong need for clear and regular interactive communications with stakeholders and resource managers.
- Challenges to develop and maintain a coherent, interdisciplinary and integrated program were identified and ideas were presented to overcome these challenges.
- Need to develop a conceptual framework to guide the remaining workshops and the program, and to facilitate integration and communication amongst group members.

Lake Michigan - Muskegon Lake
Connectivity Workshop I
2014

Dates: April 28 (1 pm – 7 pm); April 29 (8:30 am – 12:00 pm)

Meeting Place: Annis Water Resources Institute – Grand Valley State University (AWRI-GVSU), Muskegon MI

Co-Leads: NOAA Great Lakes Environmental Research Laboratory (GLERL) and AWRI-GVSU

Other Participants: Other NOAA, University of Michigan, Michigan State University, Central Michigan University, Muskegon Lake Watershed Partnership, Western Michigan Shoreline Regional Development Commission

Purpose: To develop a coordinated and collaborative research program that builds upon the efforts and strengths of AWRI in Muskegon Lake and GLERL in nearshore and offshore Lake Michigan, as well as those of others working on the watershed of the Muskegon River in order to understand the linkages between watersheds, drowned-river mouth systems, and Lake Michigan.

Goal: Link onshore, nearshore and offshore processes towards understanding and predicting the role of environmental stressors on ecosystem services, human health, and societal needs.

Objective of Workshop I: 1) Inform participants of current research around Muskegon and capabilities, 2) identify scientific needs, 3) begin dialog for developing a long-term collaborative and coordinated program in Muskegon building on all our strengths, and 4) begin planning next workshop focused on regional ecosystem restoration and management needs.

Day 1. Monday Afternoon (Moderator: Doran Mason)

Welcome (1:00 – 1:30)

- Welcome: Al Steinman (Host, AWRI-GVSU) and John Bratton (NOAA GLERL)
- Habitat restoration in Muskegon Lake – Current and future. Terry Heatlie (NOAA-Fisheries). ***Page 11***
- NOAA Habitat Blueprint – What is it and what does it mean for Muskegon Lake? Jennifer Day (NOAA) and Felix Martinez (NOAA GLERL). ***Page 17***

Summary of Discussion: *All science is local. What we learn here in Muskegon Lake can be applied elsewhere. Muskegon Lake is a microcosm of Great Lakes restoration; hence, lessons learned here could be applied to other systems. Applying research to restoration and making connections across disciplines is important. How do we coordinate the different research, activities, programs and restoration work that are ongoing in the area? 2015 is the research year for Lake Michigan under the Coordinate Science and Monitoring Initiative (CSMI).*

I. Food Web and Fisheries (1:30 to 3:30)

See individual presentation slide decks for information about current research, future research questions and needs, and areas in need of collaboration.

- Muskegon Lake - Fish. Carl Ruetz (AWRI-GVSU). ***Page 22***
- Long-term research program with spatial and process studies. Hank Vanderploeg (NOAA GLERL). ***Page 32***
- Lake Michigan Long-term observations. Steve Pothoven (NOAA GLERL). ***Page 38***
- Fish early life history and recruitment. Ed Rutherford (NOAA GLERL). ***Page 40***
- Microbial food web. Hunter Carrick (Central Michigan University). ***Page 45***
- Bacterial communities and food webs. Vincent Denef (University of Michigan). ***Page 50***
- Lake Michigan – Diporeia. Kevin Strychar (AWRI-GVSU). ***Page 53***
- Great Lakes food web modeling. Doran Mason (NOAA GLERL). ***Page 57***
- Stoichiometry and food web modeling. Jim McNair (AWRI-GVSU). ***Page 62***
- Persistent, bioaccumulative and toxic substances. Rick Rediske (AWRI-GVSU). ***Page 75***

Discussion Period I (Food Webs)

Summary of Discussion: *Several presentations outlined the portfolio of work currently being done in the Muskegon Lake and Lake Michigan nearshore area. Also highlighted was the long-term information available in GLERL databases that can be used and that can inform current and future work. The connection between the research being done in Muskegon Lake and up into the watershed highlighted the importance of the interconnection between the watershed, river, Muskegon Lake, and nearshore/offshore Lake Michigan for successful habitat restoration. Features of these large habitats interact physically, chemically, and biologically such that one affects the others. Drowned river mouths have huge wetland systems that transform inorganic nutrients into organic nutrients, but not sure how this also influences downstream nearshore lake areas.*

Group discussion focused on gaps in our knowledge, identified needs and how to identify connections among researchers. An example that dominated the discussion involved the need for a Muskegon Lake hydrodynamic model that can be linked with nearshore Lake Michigan. Can ecosystem forecasting be informed from this type of work? How transferable would this type of model be to other drowned river mouth systems along Michigan's western shoreline and throughout the Great Lakes? For example, can we create linkages between what we are doing here and apply to the St. Louis River estuary?

Another area of discussion involved the need for high frequency sampling during big flood and other episodic events. How do these events affect both the nearshore and offshore of Lake Michigan?

II. Water Quality and wetlands (3:45 – 5:30)

See individual presentation slide decks for information about current research, future research questions and needs, and areas in need of collaboration.

- Water quality: Insights from times-series observations. Bopi Biddanda (AWRI-GVSU). ***Page 80***
- Lake metabolism. Jim McNair (AWRI-GVSU). ***Page 88***
- Great Lakes HABs. Tim Davis (NOAA GLERL). ***Page 98***
- Decision support tools for HABs and hypoxia. Steve Ruberg (NOAA GLERL). ***Page 103***
- Muskegon Lake HABs. Rick Rediske (AWRI-GVSU). ***Page 107***
- Fecal Indicator Bacteria and Beach Water Quality. Eric Anderson (NOAA GLERL). ***Page 112***
- Muskegon Lake macrophytes. Al Steinman (AWRI-GVSU). ***Page 117***
- Eurasian water milfoil. Ryan Thum (AWRI-GVSU). ***Page 123***

Discussion Period II (Water quality/wetlands)

Summary of Discussion: *A summary discussion was not held after this round of presentations.*

Social mixer at the end of the first day, Monday April 28 at AWRI (5:30 – 7:00)
Dinner on your own

Day 2. Tuesday Morning (8:00-8:30 bagels and coffee, Moderator: Doran Mason)

III. Hydrology, Hydrodynamics, Observing Systems and Remote Sensing (8:30 – 10:15)

See individual presentation slide decks for information about current research, future research questions and needs, and areas in need of collaboration.

- Hydrology of coastal wetlands. Al Steinman (AWRI-GVSU). ***Page 130***
- Great Lakes Forecasting System (GLCFS). Eric Anderson (NOAA GLERL). ***Page 139***
- Ice-lake ecosystem modeling. Jia Wang (NOAA GLERL). ***Page 144***
- Great Lakes Regional Climate modeling. Brent Lofgren (NOAA GLERL). ***Page 150***
- Observing systems and instrumentation. Steve Ruberg (NOAA GLERL). ***Page 155***
- Satellite remote sensing. George Leskevitch (NOAA GLERL). ***Page 162***
- Muskegon Lake and coastal observing plans. Scott Kendall (AWRI-GVSU). ***Page 168***

Discussion Period III (Hydrology and Observing Technologies)

Summary of Discussion: *It is a complicated system but combining the hydrodynamics and chemistry and other dynamics is the way we need to go.*

Discussion once again also brought up the implications and transferability of the research to other areas in the Great Lakes.

How can satellite data help us? What measurements can be pulled out from a satellite that can look at the interface between Muskegon Lake and the nearshore of Lake Michigan?

Common themes emerged around the ideas of coupling the physiology and chemistry and the connectivity between Muskegon Lake and on and off shore of Lake Michigan. The work done here could be analogous to Chesapeake Bay. We should keep in mind that this can be a model system for other work around the world.

IV. Integrated Assessment (10:30 – 12:00)

See individual presentation slide decks for information about current research, future research questions and needs, and areas in need of collaboration.

- Forecasting the future of the Muskegon River Estuary. Ed Rutherford (NOAA GLERL). ***Page 176***
- Muskegon River: Ecosystem assessment and database framework. Ed Rutherford. ***Page 181***
- Integrated assessment: Lessons learned from Saginaw Bay. Craig Stow (NOAA GLERL)
- K-12 education and public outreach. Janet Vail (AWRI-GVSU). ***Page 186***
- AOC De-listing. Rick Rediske (AWRI-GVSU). ***Page 192***

Discussion Period IV (All sessions)

Summary of Discussion: *Craig Stow provided best practices from Saginaw Bay. The hardest part of an integrated assessment is the integration. How do we integrate our work on Muskegon Lake? How do we put the pieces together and have the parts add up to more than they are separately? We need to develop overarching themes, such as nearshore and off shore integration. We need a good conceptual model so that we can see how the pieces fit together. This conceptual model will help us integrate and to know where the different pieces connect. The conceptual model will serve as a guide to help us know where we are going.*

Communication is key and very difficult, and there is a need to overcome two fundamental challenges of communication: communication amongst principal investigators (PIs) and communication with stakeholders. Communication amongst PIs is clearly critical and is highly dependent on the individual personalities of the players and the ability of the leaders to maintain fruitful discussions. For example, in the Saginaw Bay Multiple Stressors program there were 21 PIs that communicated primarily through email. Email communication proved challenging as most PIs would not respond. Success or failure for "good" communication amongst PIs will make or break an integrated research program.

Clear and regular interactive communication with stakeholders, from the very beginning and throughout the program, is also essential for success. It is essential that we recognize stakeholders' needs and ideas, and integrate them into the program. In this respect, Muskegon has a tactical advantage - not only through a very effective PAC (Muskegon Lake Watershed

Partnership), but AWRI's strong relationship with the community. This gives the collaborative and integrated program an advantage right from the start. We should work hard to maintain this communication.

End of Workshop Observations and posed Questions:

1. *We need resources, which include financial investments from the labs, in-kind support (e.g., vessels), and personnel, and there is a need to synergistically leverage each other's work and capabilities.*
2. *How do we apply the science? GLRI is about restoration, this has been a source of funding for Muskegon habitat restoration efforts. How do we compete for these funds to build upon the restoration efforts? We need to integrate the work we are doing and focus on the problem statements that need to be solved and decision support tools. How do the models get us to the decision point?*
3. *This can be the first step in the habitat blueprint process. Making sure that we connect with improved management of the resource. What are the social goals at end of the models and how do we work backward to figure out where the gaps are?*
4. *How can the GLERL PIs work together on a single program? How do we overcome our internal divisions?*
5. *How can GLERL work more closely with AWRI?*
6. *It makes sense to develop a joint program for the long term and learn from the work we have done on Saginaw Bay.*
7. *The workshop helped to facilitate and learn about each other's interests. It was also acknowledged that getting together periodically is important for understanding who is working on what, what they are doing, and where the connections and gaps are.*
8. *The next step will make or break this project.*
9. *We need to develop a yearly planning cycle.*
10. *We should have a summary/planning meeting on an annual basis to keep us moving forward.*
11. *How does the plan for NOAA's habitat blueprint continue to build the relationship with this project?*
12. *We have seen workshops like this that launch with high energy, but then there is no follow through. We need to continue this energy and build follow through into this process.*

Next Steps:

1. *We will form a small group to develop a conceptual model.*
2. *We will have follow up workshops with managers and partners to recognize their needs into the conceptual model.*
3. *We need a structure that can be flexible and continue to evolve.*
4. *We will have a final workshop and bring in last comments.*
5. *From all of this, we need to develop a strategic plan.*
6. *We will be sharing the PowerPoint presentations and using them as the information we need to move forward.*
7. *Al Steinman will be the point of content at AWRI and Doran Mason for NOAA GLERL.*

8. *If there are those who have not been to GLERL and would like a tour of the facility please let us know. It was also suggested that GLERL and AWRI formalize an annual seminar exchange.*

Adjourn (12:00 noon)

Participant List
April, 28-29, 2014

	Last Name	First Name	Affiliation
1	Anderson	Eric	NOAA GLERL
2	Baldridge	Ashley	University of Michigan/CILER
3	Bawks	Steve	NOAA GLERL
4	Biddanda	Bopi	AWRI-GVSU
5	Bratton	John	NOAA GLERL
6	Carrick	Hunter	Central Michigan University
7	Davis	Tim	NOAA GLERL
8	Day	Jennifer	NOAA
9	Denef	Vincent	University of Michigan
10	Evans	Kathy	Muskegon Lake Watershed Partnership Western Michigan Shoreline Regional Development Commission
11	Hawley	Nathan	NOAA GLERL
12	Heatlie	Terry	NOAA Fisheries
13	Hu	Haoguo	University of Michigan/CILER
14	Kendall	Scott	AWRI-GVSU
15	Kirksey	Dennis	Muskegon Lake Watershed Partnership
16	Koches	John	AWRI-GVSU
17	Leshkevich	George	NOAA GLERL
18	Lofgren	Brent	NOAA GLERL
19	Loomis	Mark	GLNPO -USEPA
20	Martinez	Felix	NOAA GLERL
21	Mason	Doran	NOAA GLERL
22	McNair	James	AWRI-GVSU
23	Nordman	Erik	GVSU
24	Pothoven	Steve	NOAA GLERL
25	Rediske	Rick	AWRI-GVSU
26	Ruberg	Steve	NOAA GLERL
27	Ruetz	Carl	AWRI-GVSU
28	Rutherford	Ed	NOAA GLERL
29	Smart	Robert	GVSU
30	Steinman	Al	AWRI-GVSU
31	Stow	Craig	NOAA GLERL
32	Strychar	Kevin	AWRI-GVSU
33	Thum	Ryan	AWRI-GVSU
34	Vail	Janet	AWRI-GVSU
35	Wang	Jia	NOAA GLERL

Appendix: Presentations

Muskegon Lake:
a Microcosm of Great Lakes Restoration

Terry S. Heatlie
Restoration Center Great Lakes Regional Office
April 28, 2014

A Lumber Town…

Muskegon Lake shoreline during the Lumber Era

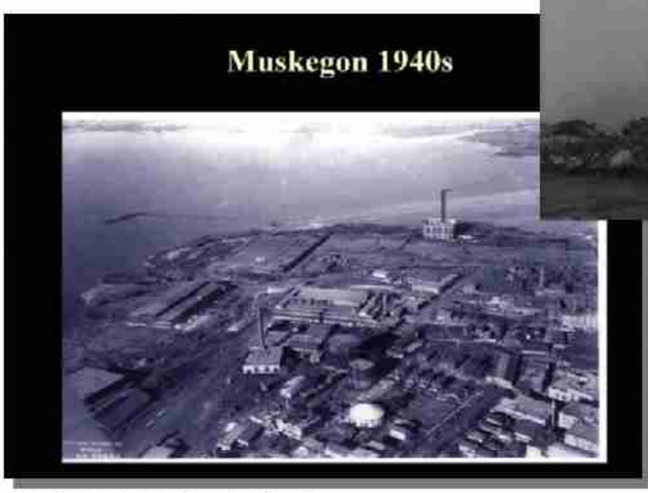
2

Mill Debris Legacy

- Slabwood
- Sawdust
- Bark

3

A Foundry Town



<u>Impacts</u>:

- 800 ac. filled bottomlands
- 74% hardened shoreline
- Excess nutrients
- Solid wastes
- contaminated sediments

Post World War II Industrial Era

4

A History of Impacts

Saw mill/foundry waste and land development → 27% open water and wetlands lost

5

Great Lakes Areas of Concern

American Recovery and Reinvestment Act (2009)

Performance Measures:

- 32.3 acres restored wetlands (vs. 23.6 ac)
- 13,073 linear ft shoreline restored (vs. 10,007 lf)
- >208,00 metric tons (vs. 182,862 mt)

American Recovery and Reinvestment Act

Before

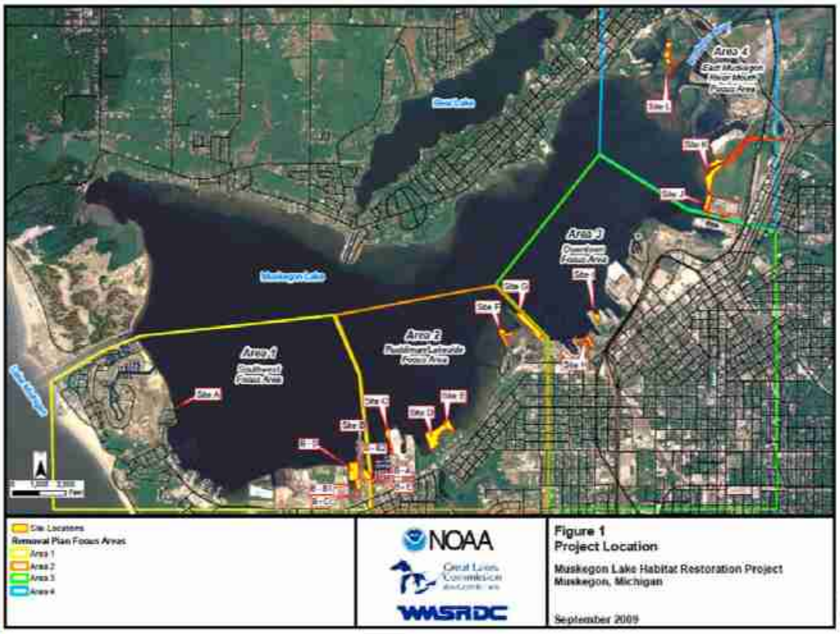
After

ARRA to GLRI and Beyond!

- 60%+ of the habitat restoration completed under ARRA
- GLRI engineering and design grant
- CELCP
- GLRI implementation
- FY14 SOW

9

American Recovery and Reinvestment Act



ARRA

?

GLLA

GLRI

CELCP

NOAA Habitat Blueprint

Jennifer Day

Habitat Blueprint Goal

To direct NOAA's

- expertise
- resources for science
- on-the-ground conservation efforts

in targeted areas (Habitat Focus Areas) to maximize our investments and the benefits to our freshwater resources and coastal communities.

www.noaa.gov

What is a Habitat Focus Area?

An area that has been selected by regional NOAA experts as a place to concentrate resources to achieve significant and demonstrable positive results and work collaboratively to achieve NOAA's habitat-related outcomes.

What we want to achieve

1. **Potential to demonstrate long term impact.**

   - If habitat conservation management actions are successful, will they lead to measureable positive impacts?

2. **Feasibility of making measurable progress in 3-5 yrs.**

   - Is there a high likelihood of measurable progress toward the desired target(s) within 3 to 5 yrs?

3. **Potential for cross-NOAA collaboration.**

   - How many programs/offices and Line Offices are likely to participate and are there opportunities for meaningful collaboration?

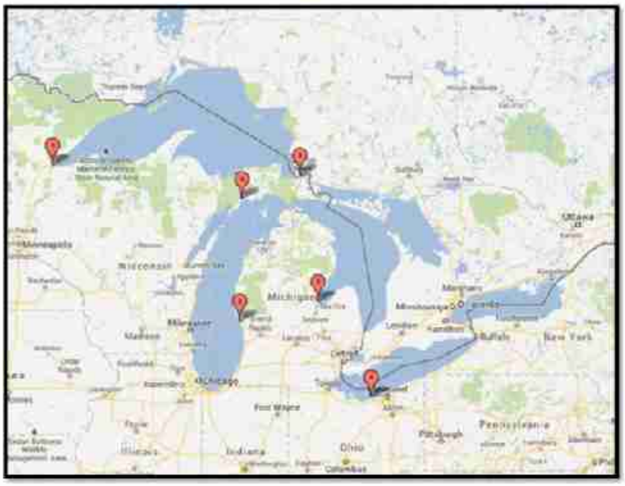
4. **External partnerships and potential to provide resources.**
    - How many external partners are likely to be involved and what is the potential to leverage external resources to achieve the primary objective(s)?
5. **Improve our scientific understanding of habitat function**
    - Will working on this issue in this area address important gaps in our knowledge of habitat function?

Additional Considerations

1. **Transferability**

    -Will the lessons learned by working on this issue in this area be transferable to other areas?
2. **Benefit to local community and economy**

    -To what extent will achieving the primary objective(s) for this area benefit the local communities and economy?



1. St. Louis River
2. Muskegon Lake
3. Manistique River
4. Black River
5. St. Marys River
6. Saginaw Bay and River

Muskegon Lake - Objectives

- Make contributions to the measurable improvement of beneficial use impairments (BUI) as specified in the area's Remedial Action Plan:
  - loss of fish and wildlife habitat
  - degradation of fish and wildlife populations
  - degradation of benthos
- Take a coordinated, cross-line office approach to the implementation of projects and the demonstration of impacts in the following areas:
  - climate coastal resiliency technical support to implement priority actions identified by the Muskegon Lake Watershed Partnership.
  - resilient coastal communities
  - increased coastal tourism, access and recreation
  - socio-economic research

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Next Steps

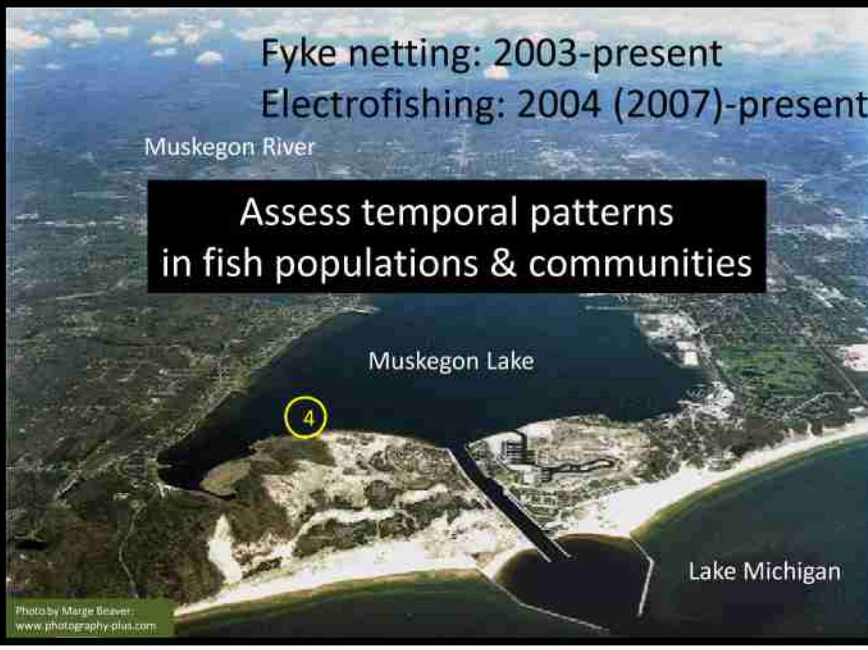
Fish population & community patterns in Muskegon Lake & other DRM lakes

Carl R. Ruetz III
ruetzc@gvsu.edu

Projects

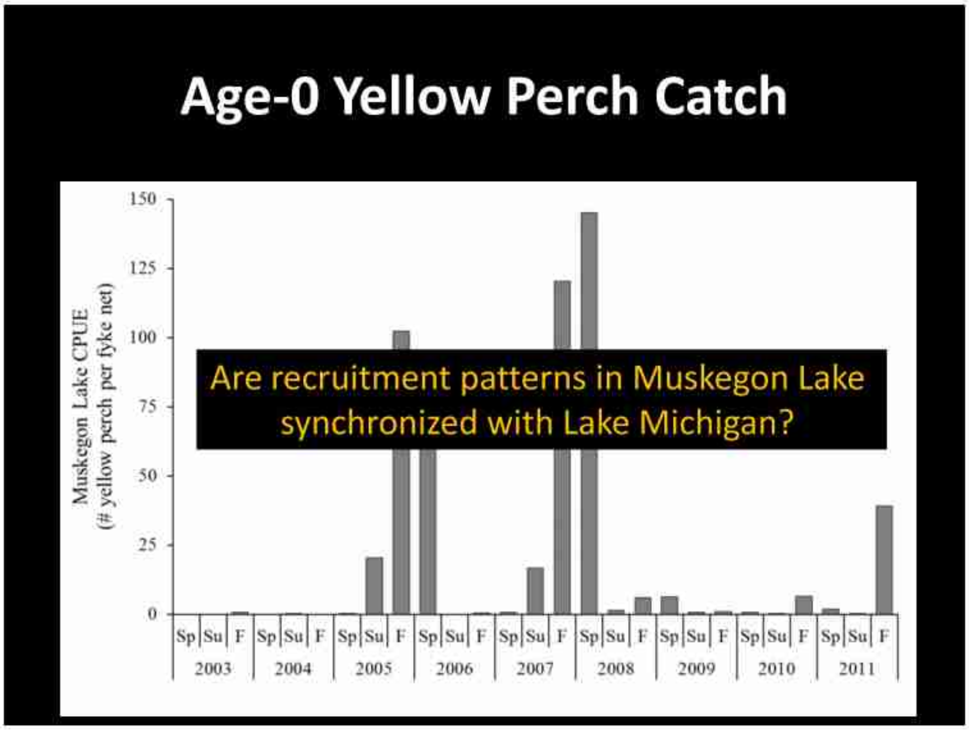
- Fish monitoring in littoral habitats
- Connectivity with Lake Michigan
  - Yellow perch
  - Lake sturgeon
- Community patterns among DRM lakes

Muskegon Lake Monitoring



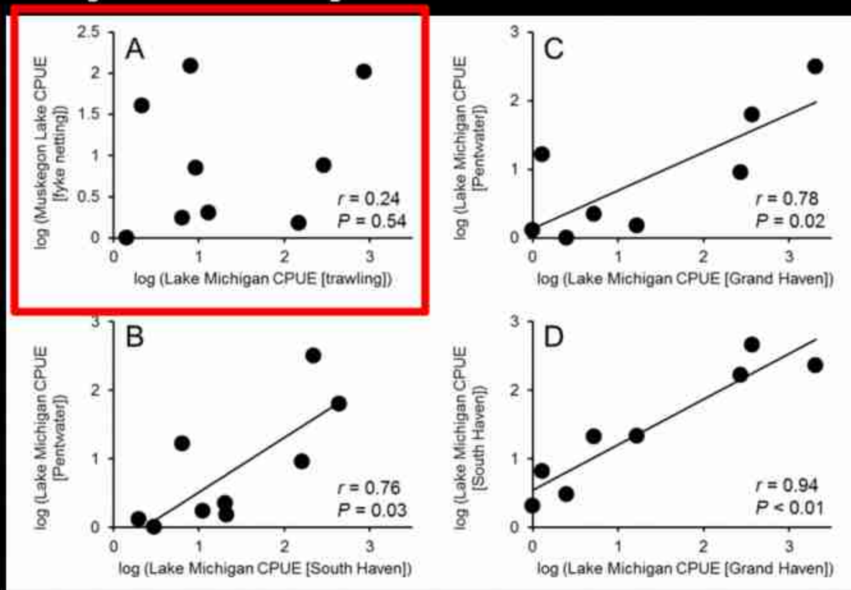
Findings

- Gears provide complimentary information (Ruetz et al. 2007, NAJFM)
- Strong seasonal & spatial variation in Muskegon Lake (Bhagat & Ruetz 2011, TAFS)


Age-0 Yellow Perch Catch
Muskegon Lake CPUE
(# yellow perch per fyke net)
150
125
100
75
50
25
0
Are recruitment patterns in Muskegon Lake synchronized with Lake Michigan?
Sp Su F Sp Su F Sp Su F Sp Su F Sp Su F Sp Su F Sp Su F Sp Su F Sp Su F
2003
2004
2005
2006
2007
2008
2009
2010
2011


Lake Michigan sampling sites
Method: Trawling (MDNR)
Fall (2003-2011)
Pentwater
Grand Haven
South Haven

Synchrony between sites?



Janetski et al. (2013, TAFS)

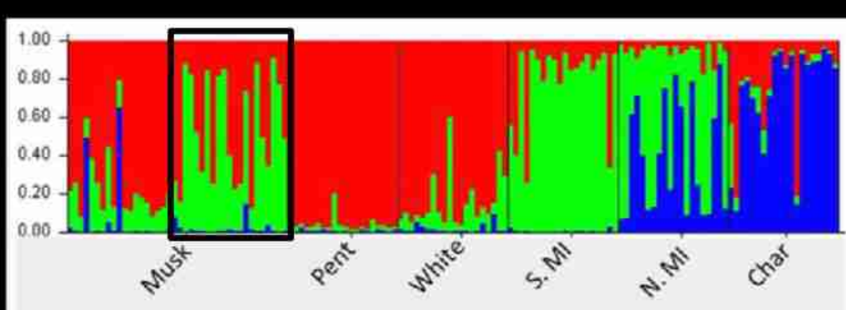
Implications

- Recruitment in DRM lakes & Lake Michigan affected by different environmental controls
- Recruitment dynamics not strongly affected by dispersal
- What is the connectivity between DRM lakes & nearshore Lake Michigan?

Yellow Perch Population Genetics

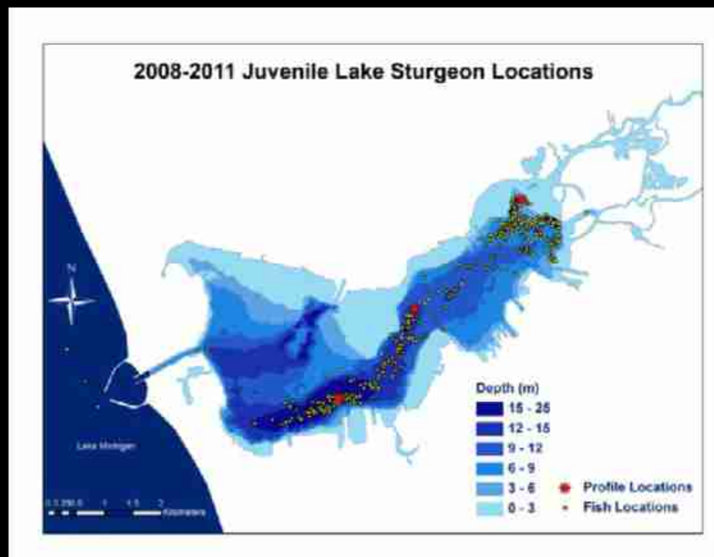
Are DRM lakes different from Lake Michigan?
Do migrants enter Muskegon Lakes?

STURCUTRE Analysis

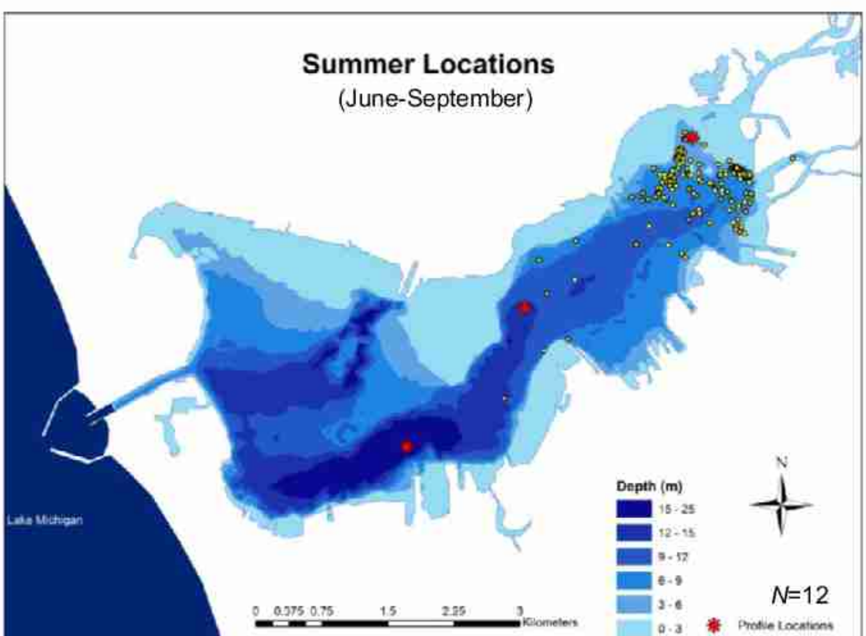


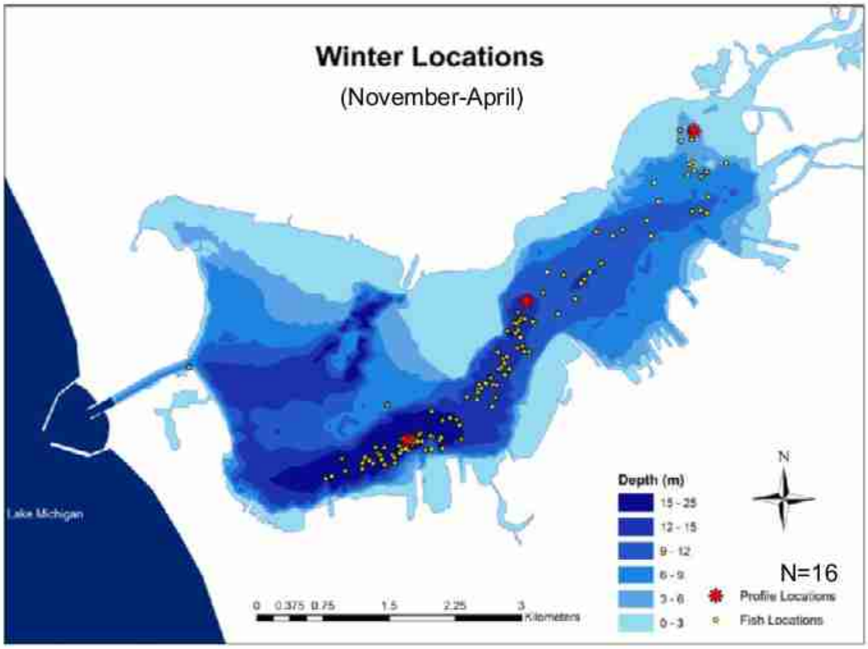
Lake Sturgeon Habitat Use

- 440 locations on 18 fish
- Two tagged fish left system

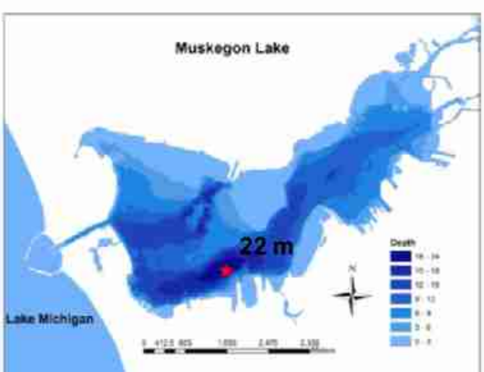


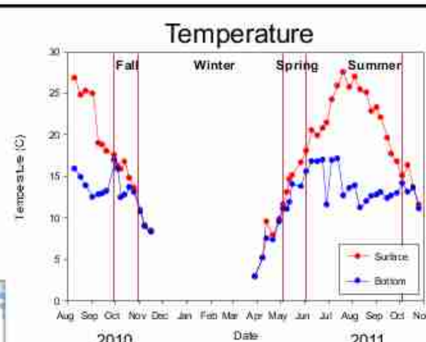
Altenritter et al. (2013, EFF)

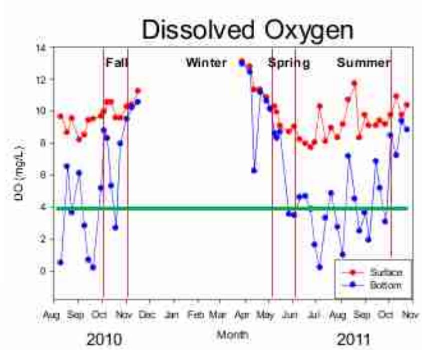




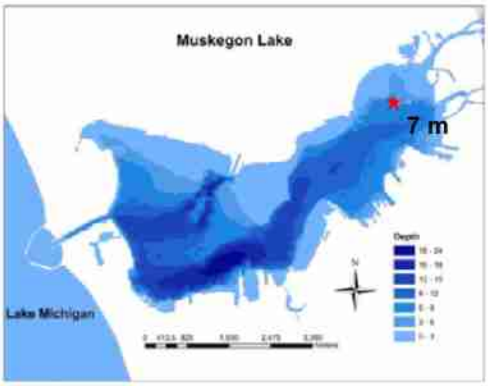
Dissolved Oxygen & Temperature: Deep Hole

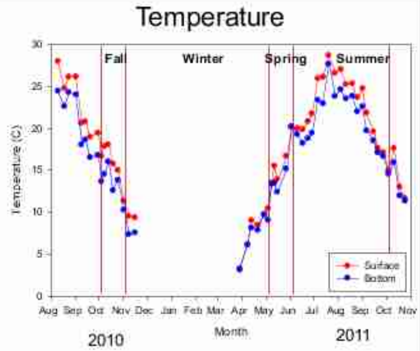




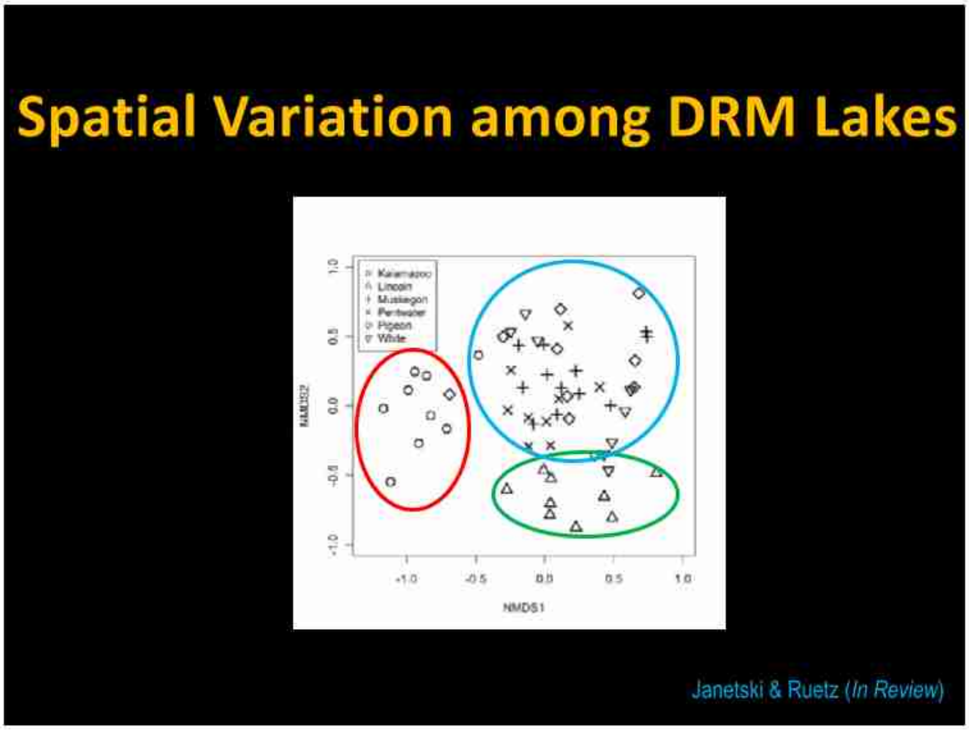


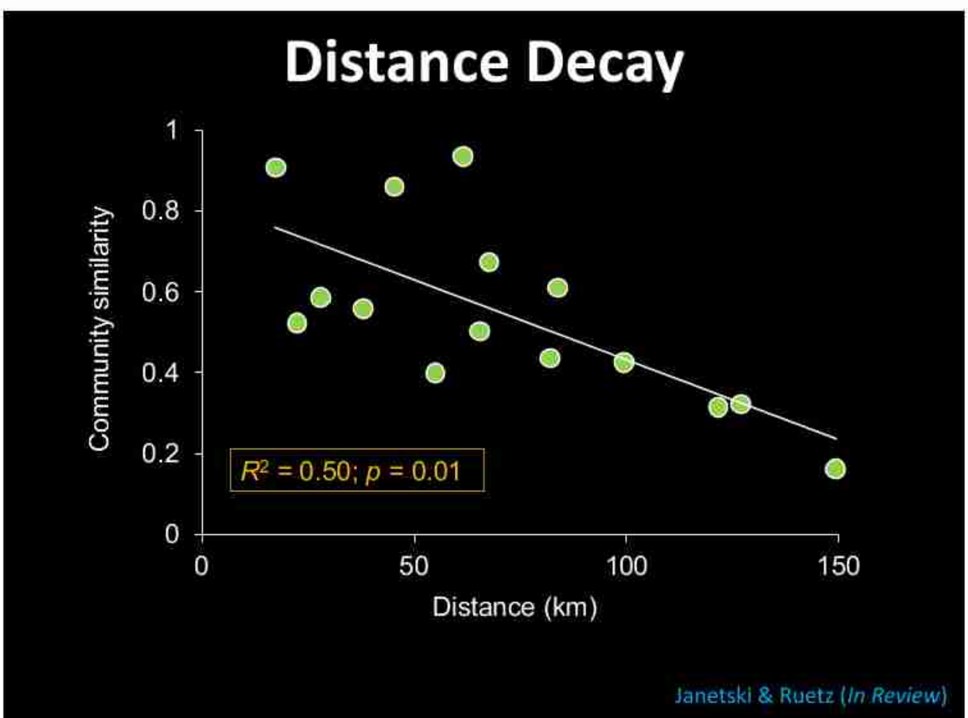
Dissolved Oxygen & Temperature: River Mouth





Patterns among DRM lakes


Spatial Variation among DRM Lakes
Kalamazoo
Lincoln
Muskegon
Pentwater
Pigeon
White
1.0
0.5
0.0
-0.5
-1.0
-1.0
-0.5
0.0
0.5
1.0
NMDS1
Janetski & Ruetz (In Review)


Distance Decay
Community similarity
1
0.8
0.6
0.4
0.2
0
0
50
100
150
Distance (km)
R2 = 0.50; p = 0.01
Janetski & Ruetz (In Review)

Research Opportunities

- Biological connectivity between DRM lakes & Lake Michigan
  - Strength of connection?
  - Seasonal timing?
  - Metacommunity framework?
- Importance of DRM-lake habitats in nearshore Lake Michigan food web?

Spatial studies and microbes
Process studies associated with mussels
Lake Michigan CSMI 2015

Henry Vanderploeg
NOAA GLERL

EcoDyn Team (Branch) carries out a long-term research (LTR) program (mostly at Muskegon)

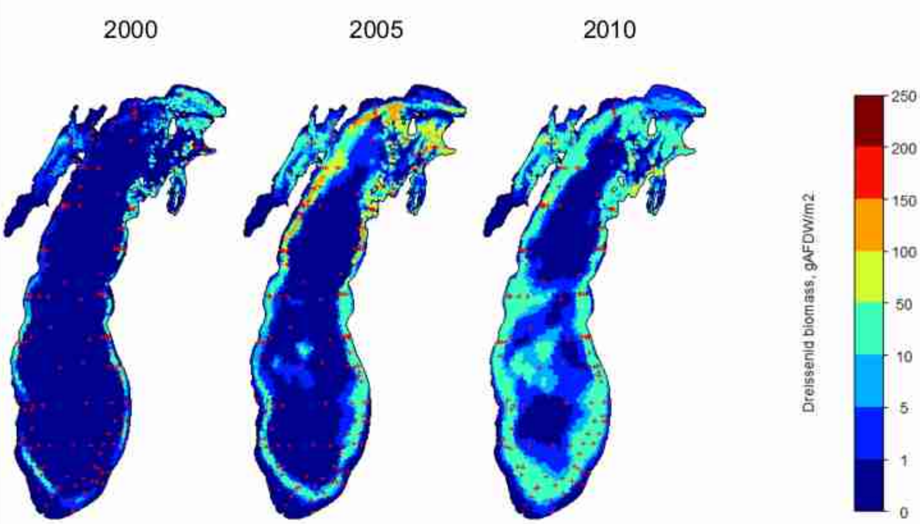
- Monthly/biweekly core pelagic monitoring program
- Moorings for physical variables
- Dreissenid abundance
  - Annual southern basin survey
- Spatial studies and Microbes
  - Food web from microbes to fish
- Process studies
  - Benthic boundary layer
  - Mussel feeing and nutrient excretion
  - Microcystis ecology (Cross-Branch Lake Erie)
- Year of Lake Michigan 2015

Spatial Studies and Microbes

Three "seasonal" cruises (April, July, September

- GLERL pelagic food-web team (Vanderploeg, Cavaletto, Liebig, Mason, Rutherford) and CMU (Carrick) and UM (Denef) partners
- Instrumentation (Ruberg, Constant) & data analysis (Lang) teams
- Benthos team (Nalepa, Vanderploeg, Rowe, new hire to arrive soon)

The driver: spatial distribution of dreissenid biomass

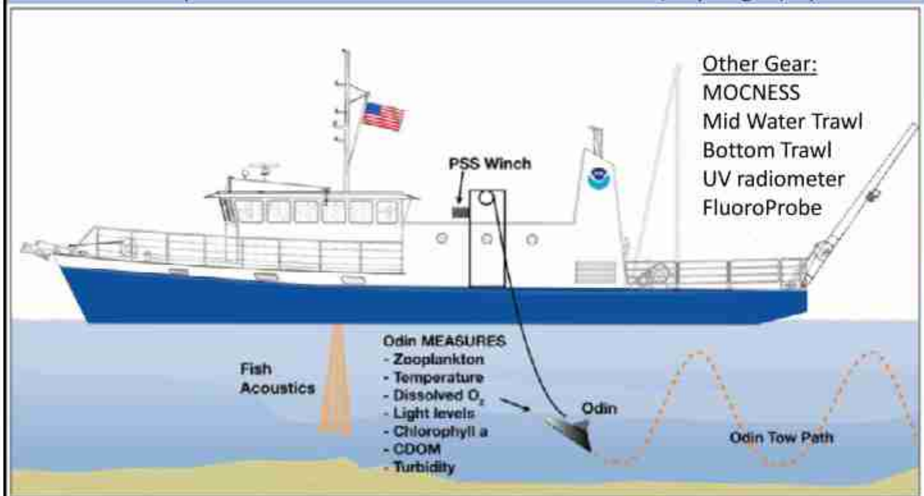


Reanalysis of Nalepa's spatial data showing "mid-depth sink" by Mark Rowe –NRC postdoc

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / GREAT LAKES ENVIRONMENTAL RESEARCH LAB / ANN ARBOR MI

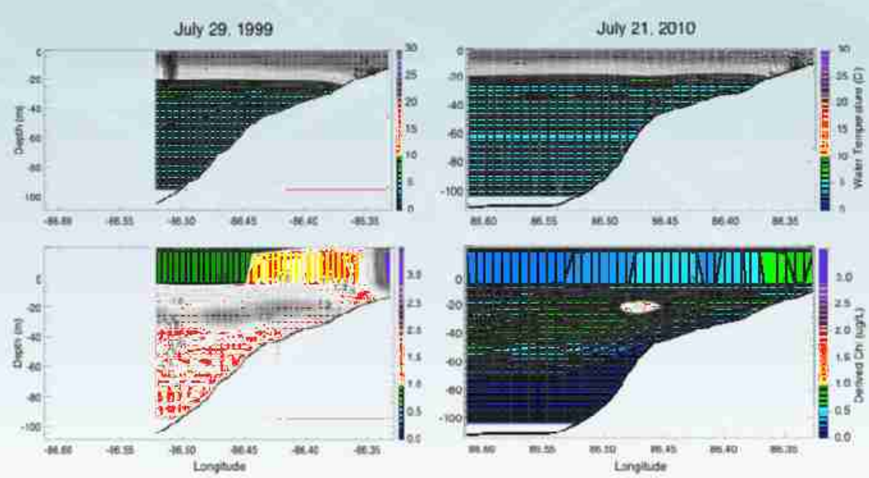
NRC Research Associateship Programs

Recent directions and technology: Spatial Studies & Microbes—spatial coupling of physical variables, nutrients and all food web components from microbes to fish over diel (day-night) cycle

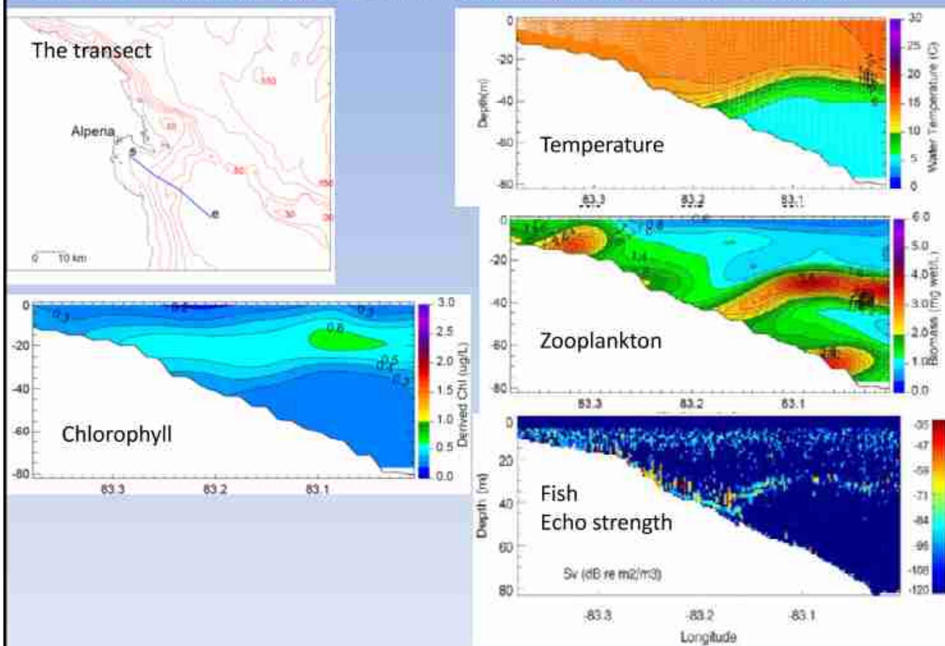


On board measures include: nutrients as well as microbial food web abundance (microscopy and –omics), and function by GLERL Food Web Team and UM and CMU partners

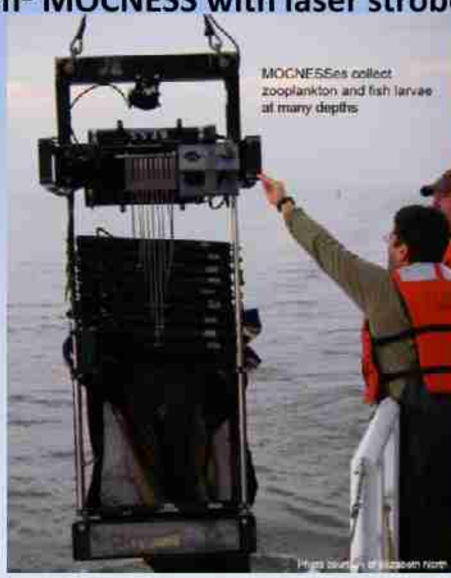
Demonstartion of changes in Lake Michigan: Big change summer



Lake Huron—September day 2012: There is extreme spatial organization of food web



New purchase to improve spatial studies:
1-m² MOCNESS with laser strobe unit



Fine-scale distribution of predators and prey:
- •Larval fish
- •Bythotrephes
- •Large and small zooplankton
- •Mysis

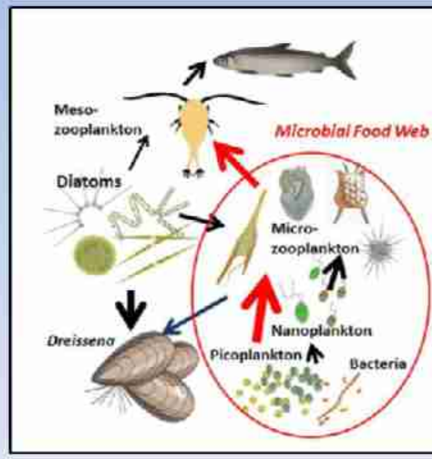
Lake Michigan Process and Spatial & Microbes Studies

Results of experiments (& observations):

- Mussels filtering and nutrient sequestration have decimated spring phytoplankton bloom (Vanderploeg et al. 2010)
- 70% of phytoplankton are < 2µm (April-May 2013 observations—Hunter Carrick)

Implications:

- Shift focus to picoplankton & MFW
- New tools and partnerships are necessary
- New models are necessary



Process and modeling studies

- Ongoing studies on feeding and nutrient excretion by quagga mussels continue
- Coupled physical and biological models to predict impact of mussel grazing and nutrient excretion are being built (Mark Rowe NRC posdoc, Jia Wang, and Eric Anderson)

GLERL Studies for Lake Michigan 2015 CSMI—with help from EPA

1. Whole Lake Benthic Survey (with help from Tom Nalepa)
2. Spatial Structure (and function) of Food Web—including Primary Production and MFW (GLERL Food Web Team, CMU and UM?) monthly in Muskegon/Grand Haven Region
3. Mussel grazing/nutrient excretion/MFW?

Lake Michigan Long-term Research

Steve Pothoven

National Oceanic and Atmospheric Administration
Great Lakes Environmental Research Laboratory
GLERL

Lake Michigan long-term research

- Grand Haven 100 m/Muskegon 110 m
  1983-2013
- Muskegon 40-45 m
  1996-2013
- Muskegon 15 m
  1998-2013
- Other misc. sites
  Muskegon Lake (1995-1998)
  Nearshore transect

Long-term research activities

March-December (as conditions permit)
1-2 samples/month

- temperature/fluorometer/transmissometer profiles
- Nutrients (TP, PP, SRP, SiO_2, CHN) at depth
- Chlorophyll *a* at depth
- Zooplankton-whole water column
- *Mysis*-whole water column
- *Diporeia*/Mussels (seasonal)
- Overwinter and summer moorings (temp/fluorescence)

Long-term research fisheries activities

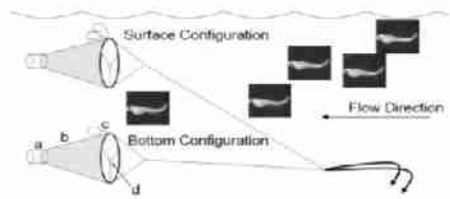
- 1998-2014
- Done as needed/as resources available
- Planktivore diets and feeding ecology
- Planktivore condition
    - Energy content

Fish Early Life History and Recruitment

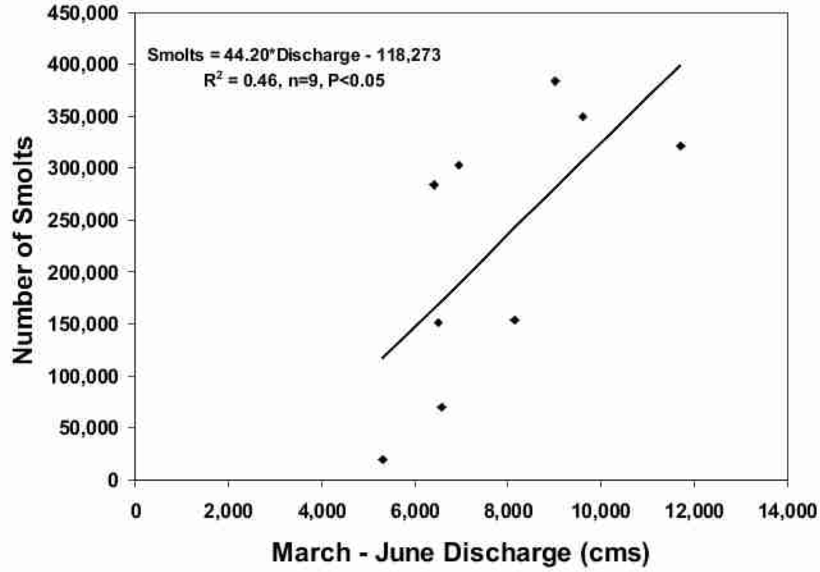
Ed Rutherford

Muskegon Workshop April 28, 2014

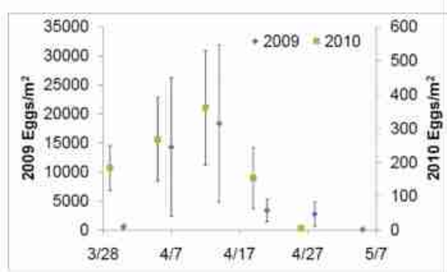
Lower Watershed Studies

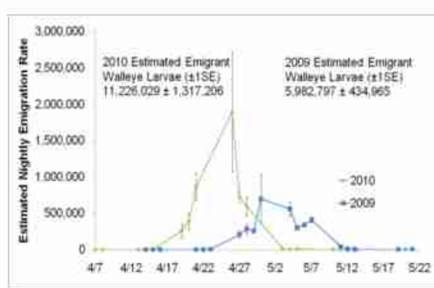


Salmon Recruitment Positively Affected by River Flow, Cold Temperatures

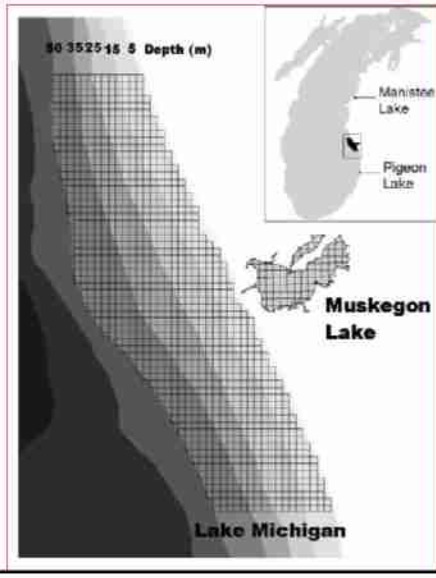


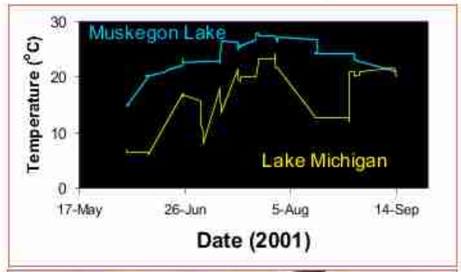
Walleye? …just the opposite





Muskegon Lake is warmer and more productive than nearshore Lake Michigan

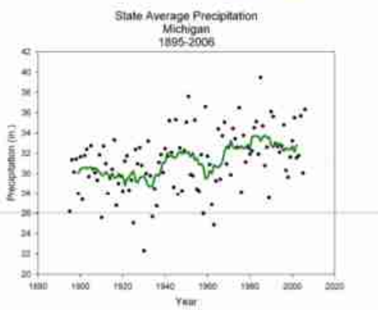


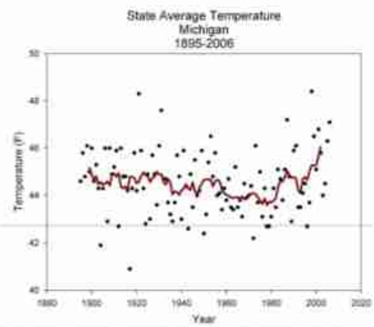


Slight Decline in Alewife Growth, not Density after spring bloom crash

	2001-2002 Höök et al. (2007)	2010
Growth Rate (mm/d) 	0.70-0.72 ± 0.02	0.64 ± 0.02 n=115
Mean Density (May-Aug) (#/1000m^3)	8.0 ± 0.3	8.2 ± 3.4

Common Stressors affecting Fish Recruitment In MRES

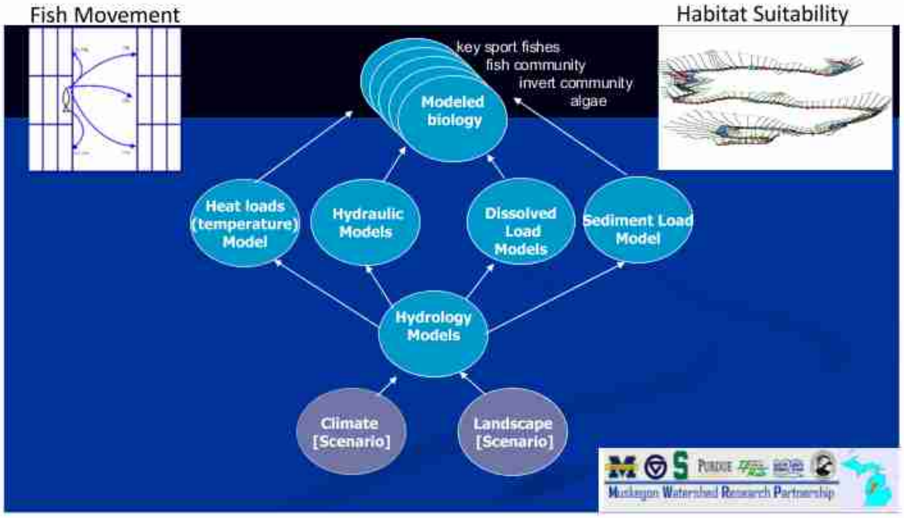




Modeling land use and climate change

Fish Movement

Habitat Suitability



Future Research Areas

- Is Muskegon Lake a nursery area,
  a predation gauntlet, or both?
- Link lake physics to fish recruitment.
- Model multi-stressor impacts on food webs and fish recruitment
- Relative importance of habitat protection and restoration

Importance of the Microbial Food Web in a Changing Lake Michigan

Contributors

Hunter Carrick, Emon Butts, Chris Frazier, Andrew Stimetz
Central Michigan University

Peter Lavrentyev
University of Akron

Gary Fahnenstiel, Erin Cafferty
Michigan Technological University

Henry Vanderploeg
GLERL/NOAA

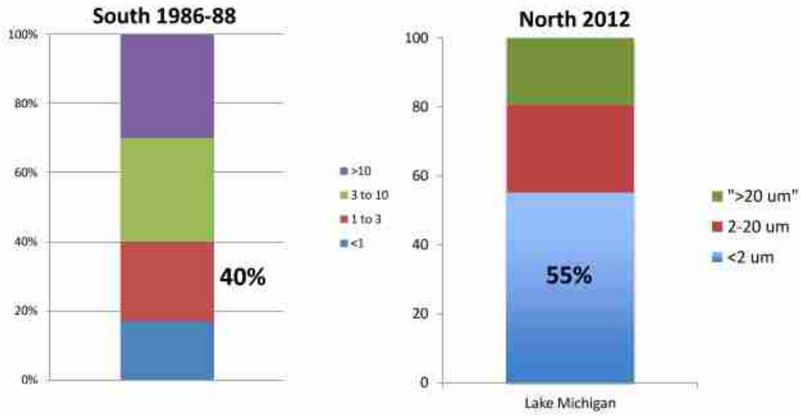
Rationale

- Unprecedented changes observed in the open water region of southern Lake Michigan.
- The scope of the changes are currently unknown (time, space): no typical spring bloom, shift zoops
- Measure biomass, taxonomic composition, and growth/loss rates for phytoplankton and components of MFW (bacteria, algae, protists).
- *Given their swift growth and adaptive capabilities, we hypothesize that components of the MFW will have a compensatory affect on the fishery.*

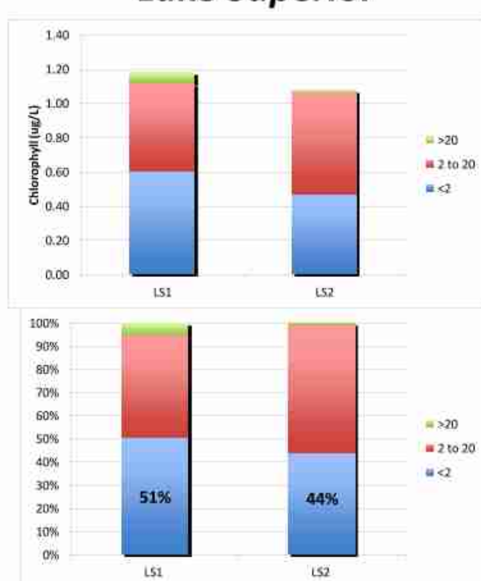
Field Sampling & Measurements

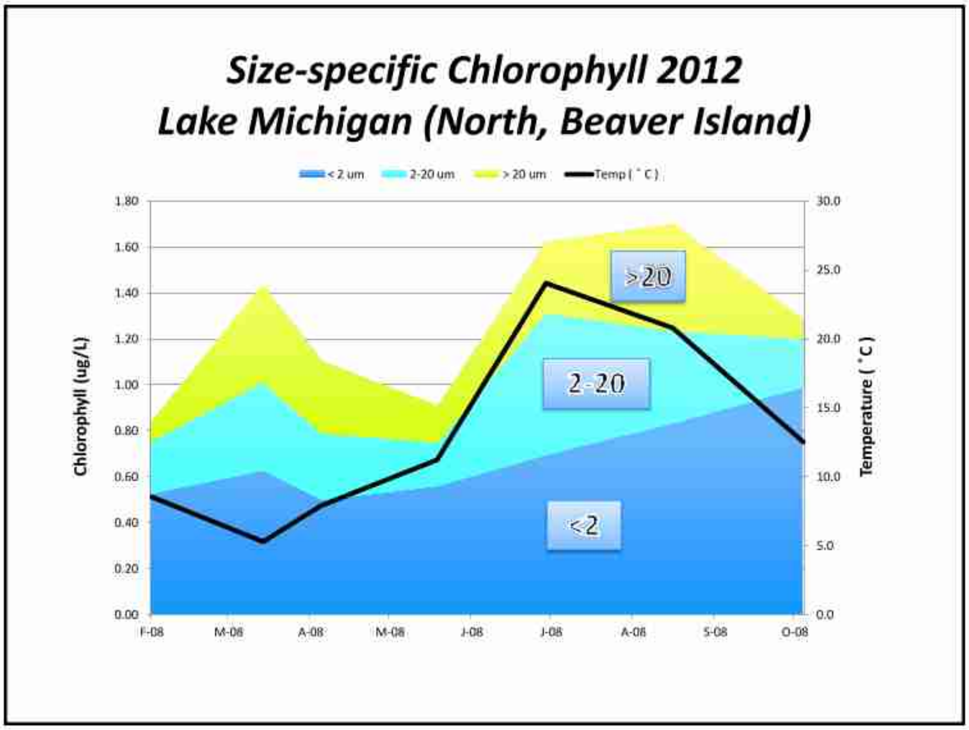
- Sites sampled from small and large research vessels.
- Data collected from three lake sites:
  - Superior: Houghton (2)
  - Northern: Beaver Island (1, 4)
  - Southern: Muskegon (3)
- Ambient conditions monitoring using CTD and data Sondes.
- Water column strata sampled using Niskin bottles.
- Chlorophyll determined (2-um, 20-um, and whole).
- Bottle experiments to measure prokaryotic picoplankton growth and loss rates (antibiotic inhibitor).

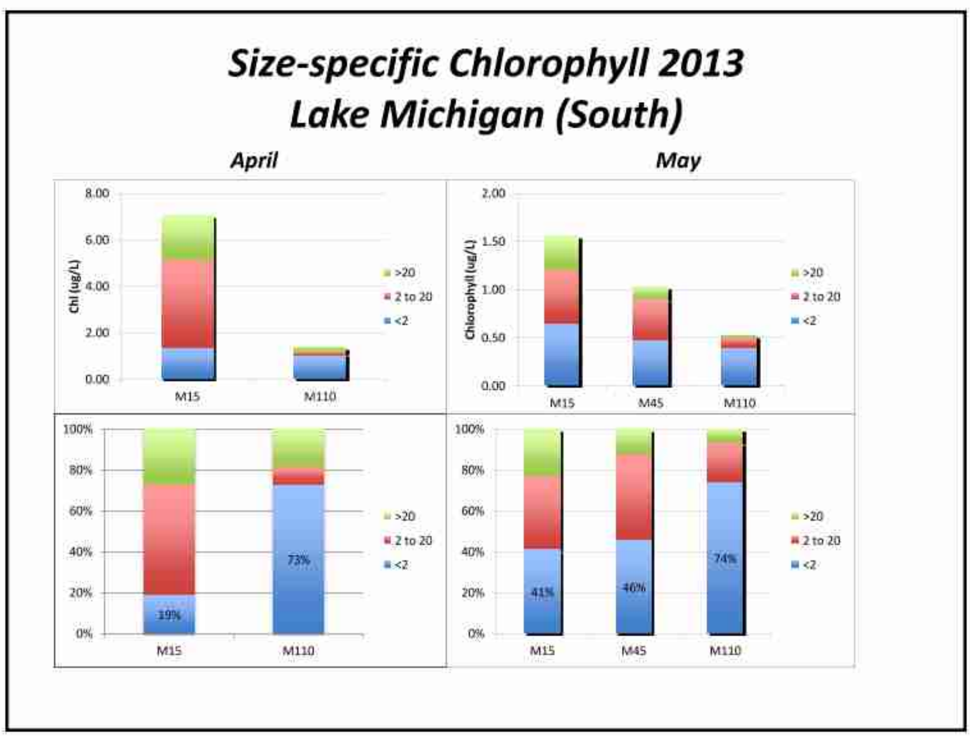
Size-Specific Chlorophyll 1980's vs. 2012 (Annual Average)



Size-specific Chlorophyll 2013 Lake Superior




Size-specific Chlorophyll 2012
Lake Michigan (North, Beaver Island)
< 2 um
2-20 um
> 20 um
Temp (°C)
Chlorophyll (ug/L)
Temperature (°C)
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
30.0
25.0
20.0
15.0
10.0
5.0
0.0
>20
2-20
<2
F-08
M-08
A-08
M-08
J-08
J-08
A-08
S-08
O-08


Size-specific Chlorophyll 2013
Lake Michigan (South)
April
May
Chl (ug/L)
Chlorophyll (ug/L)
8.00
6.00
4.00
2.00
0.00
2.00
1.50
1.00
0.50
0.00
>20
2 to 20
<2
M15
M45
M110
100%
80%
60%
40%
20%
0%
19%
73%
41%
46%
74%

Picoplankton Growth & Loss Rates 2013
(50 experiments; cv about replicates ~50%)

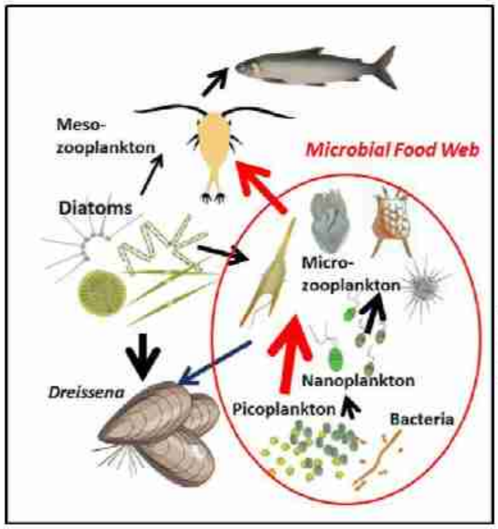
Lake	No. Exps	Hpico Growth Per day	Hpico Loss Per day	Ppico Growth Per day	Ppico Loss Per day
Superior Epi	18	0.515	-0.963	0.215	-0.203
Superior Meta	15	0.553	-1.104	0.196	-0.251
Michigan North	6	0.289	-0.313	0.383	-0.232
Michigan South	11	0.535	-0.158	0.188	-0.328
	X sd	0.473 +/- 0.124	-0.635 +/- 0.469	0.245 +/- 0.092	-0.253 +/- 0.053

Abundance of MFW Components (SLM) Comparison 1990 to 2013

Type	Plankton Group	1989-90	2013	Result
Photo	Chlorophyll ug/L	1.5 to 3.0	0.5 to 1.7	2-fold decline
Photo	Nanoflagellates pigmented	300 – 1,900	280 – 2,043	No change
Photo	Microflagellates pigmented	0.4 – 7.4	2.0 – 8.0	No change
Hetero	Nanoflagellates colorless	600 – 5,000	717 – 3,121	1.6-fold decline
Hetero	Ciliates colorless	2.0 – 14.0	0.4 – 4.2	3.3-fold decline

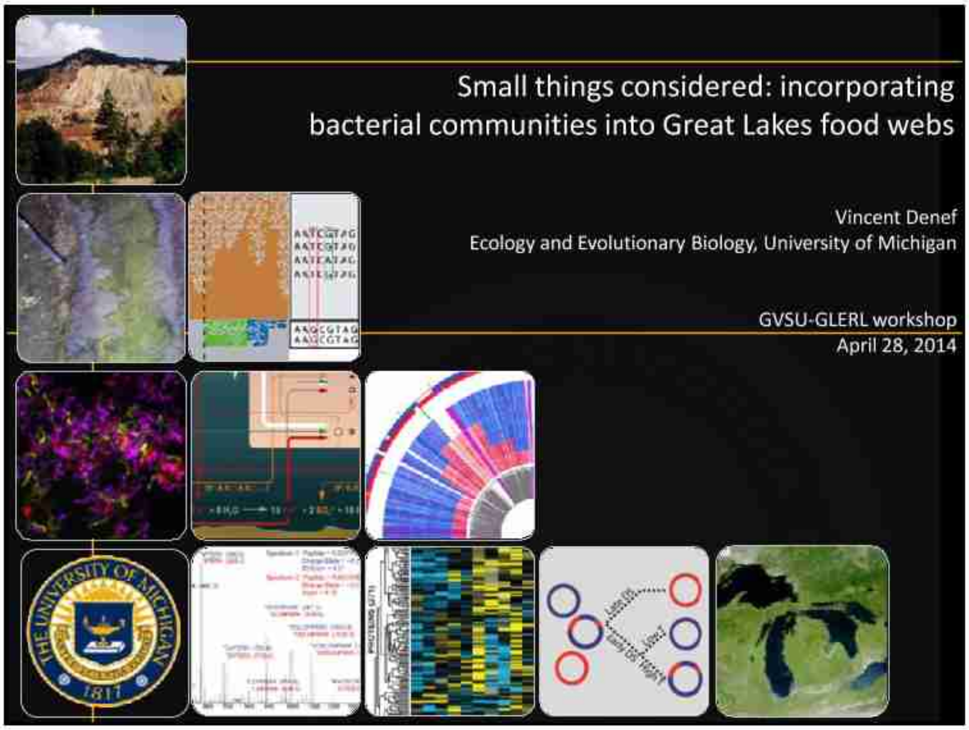
Identical methods used in 1989-90 and 2012-13

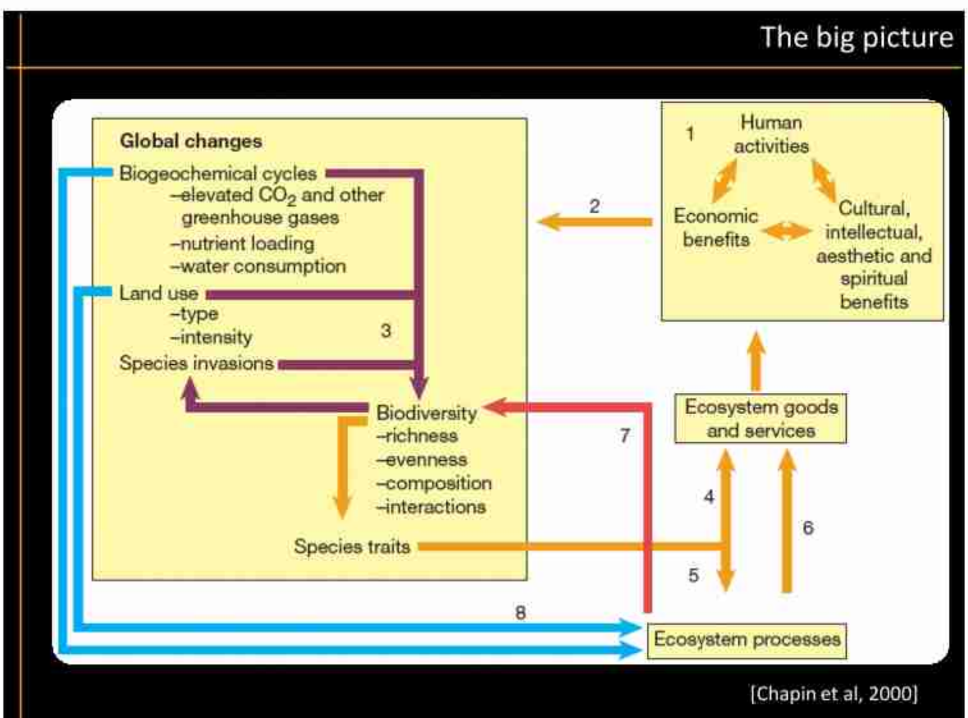
Interpretation



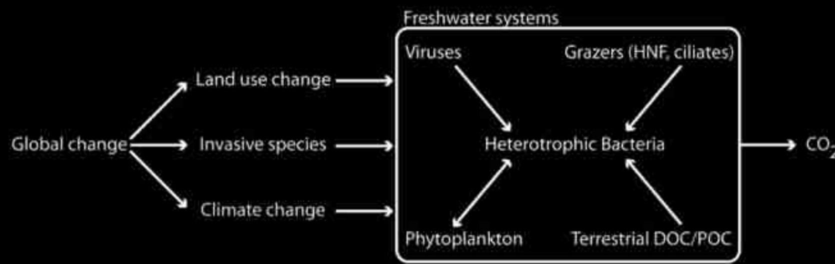
Abundance
High Turnover
Relative Stability?

Enhance resolution (time, space)
Rapid measurements (PAM fluorometry, flow cytometry-NSF)


Small things considered: incorporating
bacterial communities into Great Lakes food webs
Vincent Denef
Ecology and Evolutionary Biology, University of Michigan
GVSU-GLERL workshop
April 28, 2014
THE UNIVERSITY OF MICHIGAN
1817


The big picture
Global changes
Biogeochemical cycles
–elevated CO_2 and other greenhouse gases
–nutrient loading
–water consumption
Land use
–type
–intensity
Species invasions
Biodiversity
–richness
–evenness
–composition
–interactions
Species traits
1
Human activities
Economic benefits
Cultural, intellectual, aesthetic and spiritual benefits
2
3
4
5
6
7
8
Ecosystem goods and services
Ecosystem processes
[Chapin et al, 2000]

Freshwater microbial evolutionary ecology



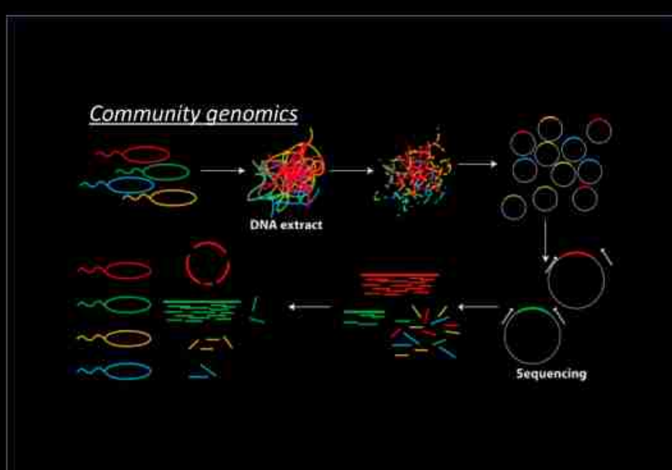
(i) How does human disturbance drive microbial ecological dynamics?

(ii) How do microbial community level responses affect ecosystem functioning, particularly the balance between carbon storage and respiration?

(iii) What is the role of fine-scale evolutionary processes in microbial adaptation to change, and how does it impact ecosystem functioning?

Life through the omics view

Microbial ecological dynamics (changes in community structure and behavior)



Global change and the Great Lakes carbon cycle

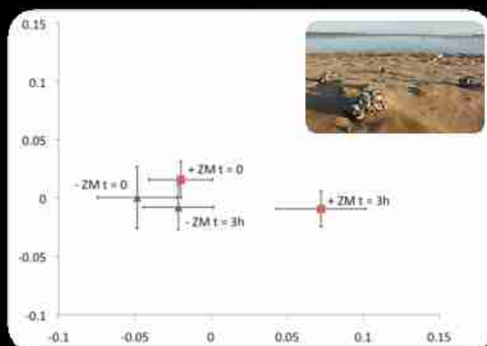
Great Lakes and the global carbon cycle:

✓ Net CO_2 emissions from freshwater systems rival CO_2 uptake by the oceans

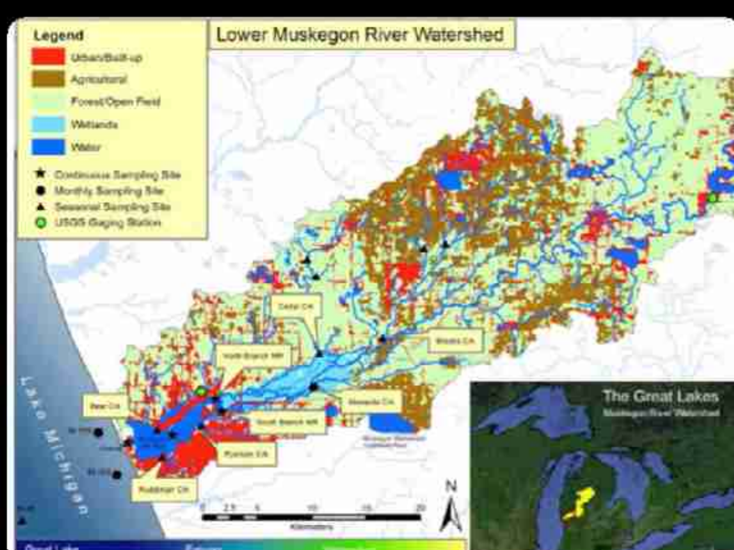
✓ Heterotrophic bacteria key to autochthonous and allochthonous carbon processing

✓ Carbon cycle and microbial drivers of this cycle are understudied in GL

✓ZM/QM invasion has concentrated fluxes in nearshore/benthic environments



GVSU-GLERL



Decline of *Diporeia* in the Great Lakes: Was the primary factor disease?

Kevin Strychar

Decline of *Diporeia*

- Steady decline since the 1980's up to 95%
- Affecting food-webs + fish industry (e.g. whitefish)
- Tom Nalepa:
  - Caused by AIS zebra mussels
  - Food competition
- Dave Fanslow:
  - Caused by disease

Methods

Figure 1. (A) Research vessel (~7.3 m) provided by NOAA-GLERL; (B) Ponar grab used for sediment collection; (C) Bottom sediment collected with a ponar grab sampler; (D) Collection of *Diporeia* from filtered bottom sediment.

Methods

- Linear Regression
- Chi-square analysis

Results

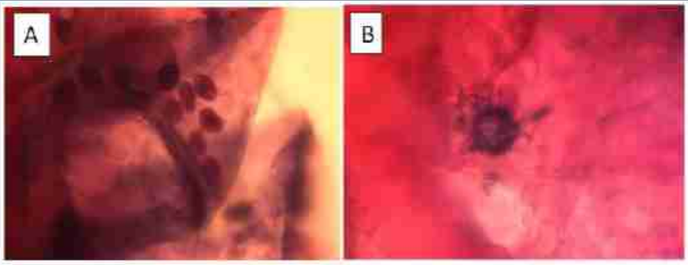


Figure 6. Analysis using fluorescent microscopy. **(A)** Basophilic bodies observed at 400x magnification. Bodies were observed in close proximity to one another. **(B)** Budding structure observed at 400x magnification. These structures were typically observed as scattered masses throughout the body of the *Diporeia*.

2005 – 19% were infected; 2010 30% were infected; 2014?

2005 – 64% had disease symptoms; 2010 83% show disease symptoms; 2014?

Results

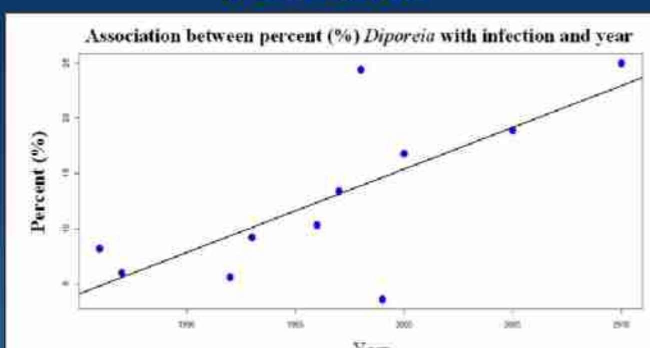


Figure 7. Linear regression modeling showed a significant positive linear association between percent of *Diporeia* exhibiting a pathogenic infection and year (r=0.7202261, p-value=0.0124).

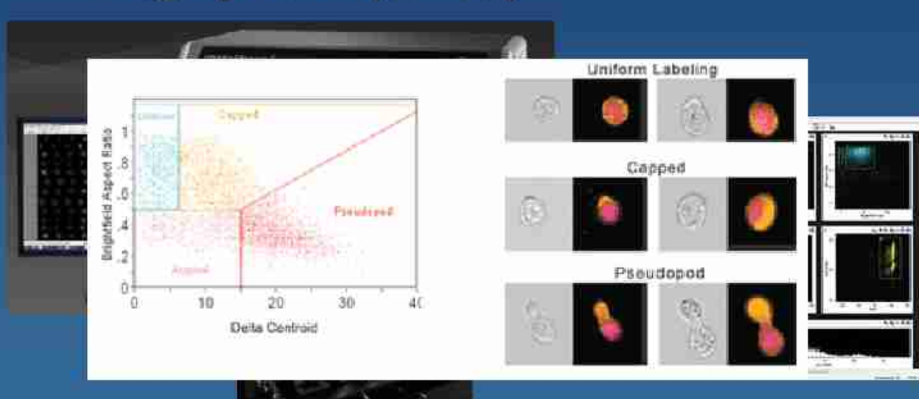
Chi-square testing for independence was also used to test if there was an association between year and percent infection. Values obtained were $X^2 = 50$, df = 10, p-value<0.0001, implying significant association between year and infection.

Conclusions

- Disease may have played a factor in *Diporeia's* decline
- Zebra mussels and possibly other AIS (e.g. Quagga mussels; *Dreissena rostriformis*) may have acted as the vector for pathogen(s)

Next Steps

- Examine zebra and quagga mussel tissue
- Live studies of potential infection
- Imaging Flow Cytometry



Great Lakes Food Web Modeling

Doran Mason

April 28, 2014

Great Lakes Food Web Models

Fish Recruitment, Production and Movement

- Individual-based community
- Larval advection and survival
- "Fish-Here!": Spatial Distribution Simulator

Food Web and Ecosystem Response

- Individual-based community
- EcoPath with EcoSim (EwE)
- Atlantis Ecosystem Model

Anthropogenic Stressors

- Climate Change
- Invasive Species
- Eutrophication/Hypoxia
- Contaminants
- Fishing

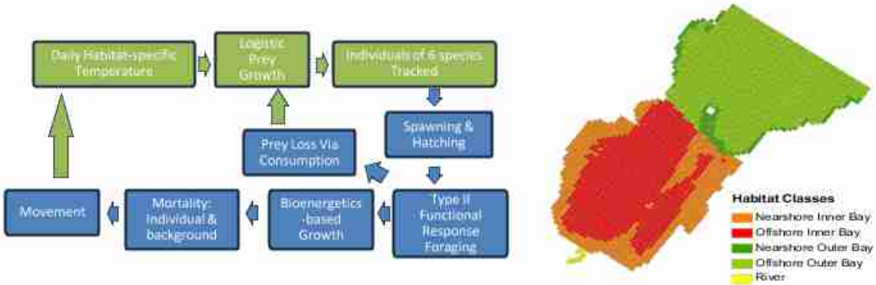
CILER NATURAL RESOURCES AND ENVIRONMENT UNIVERSITY OF MICHIGAN

National Centers for Coastal Ocean Science Center for Sponsored Coastal Ocean Research

GLERL

Great Lakes RESTORATION

Individual-Based Community Model

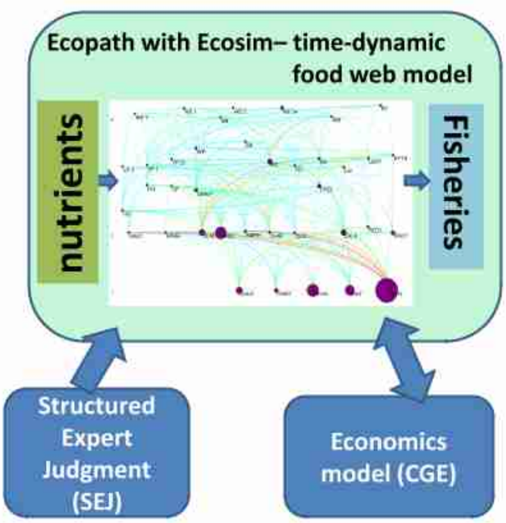


PREY= phytoplankton, zooplankton, benthos, dreissenids, forage fish, detritus
Fish= walleye, yellow perch, round goby, rainbow smelt, ***silver and bighead carp***

Ecosystems
- Lake Michigan
- Lake Huron
- Lake Erie

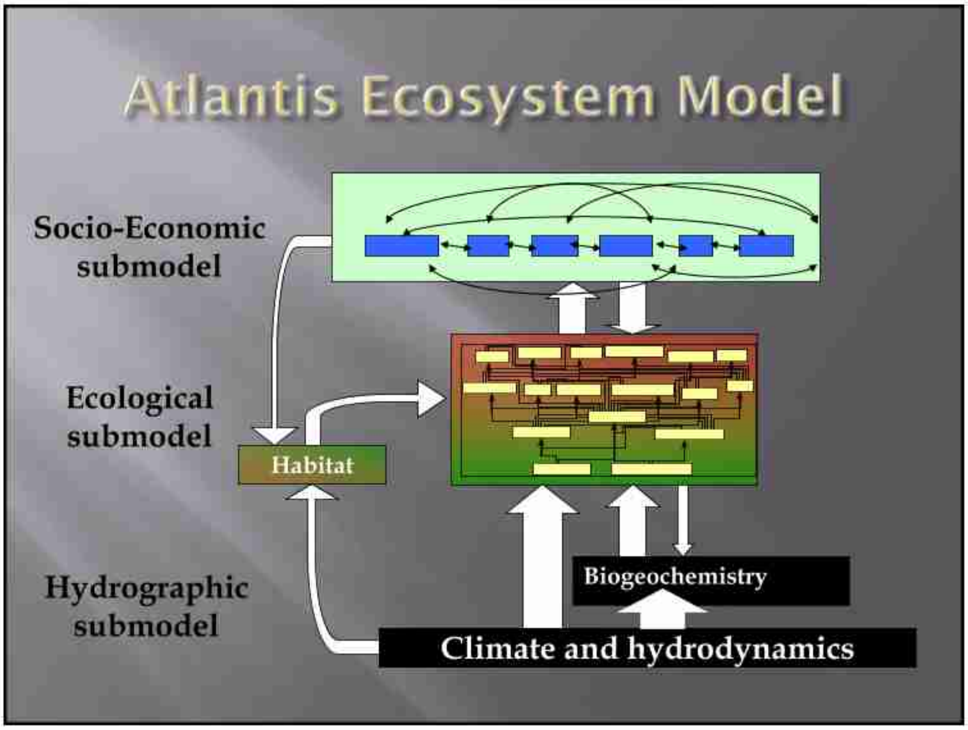
Stressors
- Invasive species
- Climate change
- Contaminant accumulation

EwE Incorporating Uncertainty and Linked to Economics

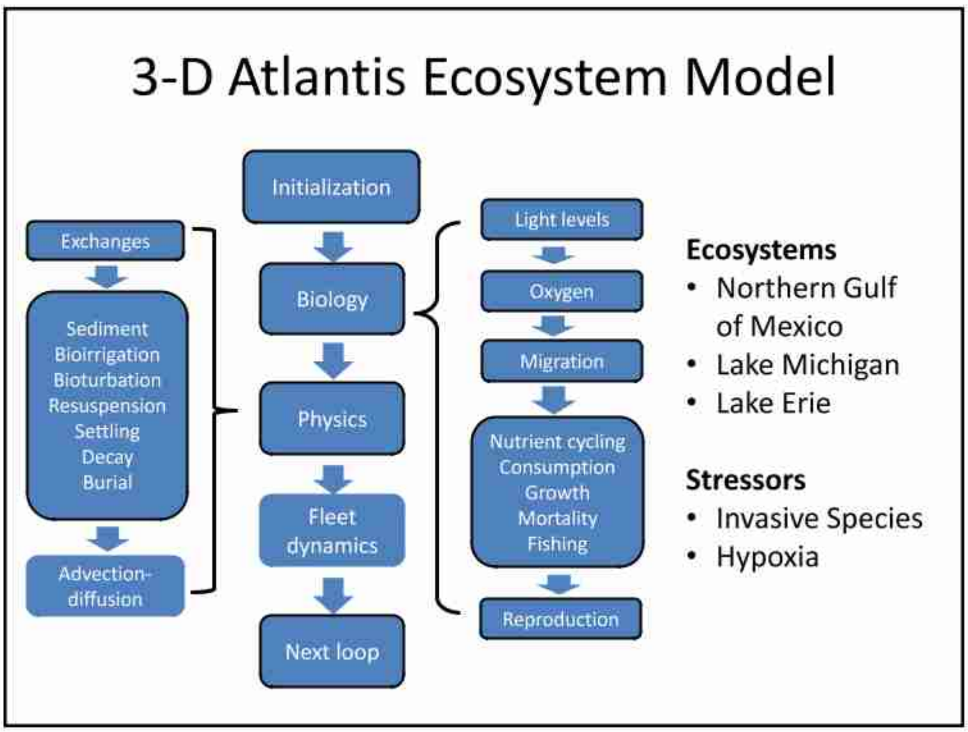


Ecosystems
- Lake Erie
- Lake Huron
- Lake Michigan
- Lake Ontario

Stressors
- Invasive species
- Hypoxia
- Eutrophication
- Contaminant bioaccumulation

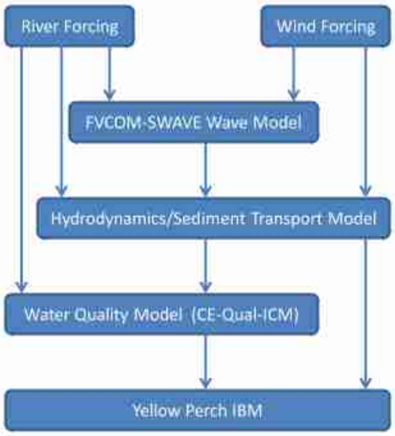


Atlantis Ecosystem Model
Socio-Economic submodel
Ecological submodel
Habitat
Hydrographic submodel
Biogeochemistry
Climate and hydrodynamics



3-D Atlantis Ecosystem Model
Initialization
Biology
Physics
Fleet dynamics
Next loop
Exchanges
Sediment
Bioirrigation
Bioturbation
Resuspension
Settling
Decay
Burial
Advection-diffusion
Light levels
Oxygen
Migration
Nutrient cycling
Consumption
Growth
Mortality
Fishing
Reproduction
Ecosystems
• Northern Gulf of Mexico
• Lake Michigan
• Lake Erie
Stressors
• Invasive Species
• Hypoxia

Fish Recruitment: Larval Advection and Survival



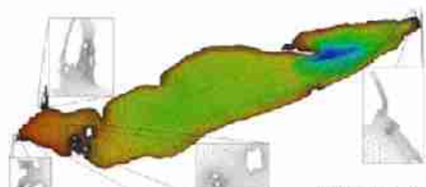
Model framework with arrows indicating linkages between model components

Ecosystems

- Lake Erie
- Lake Michigan

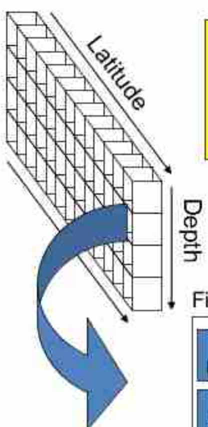
Stressors

- Nutrient loading
- Climate change



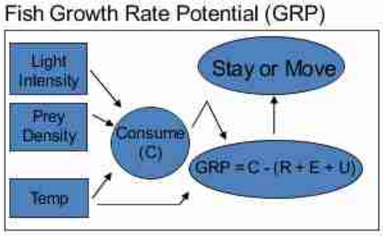
FVCOM grid

"Fish Here!": Forecasting Great Lakes Fish Distributions and Movements



Hydrodynamics Model (POM):
3-D Circulation
Thermal Structure
2 km horizontal grid
20 vertical (sigma) levels

Fish Growth Rate Potential (GRP)



Ecosystems

- Lake Michigan
- Lake Ontario

Stressors

- Climate Change
- Overfishing

Gaps and Opportunities

- Time series for critical food web components
- Values for parameters
  - Biomass
  - Production
  - Consumption

Stoichiometry and aquatic food web models

Jim McNair, Bopi Biddanda, and Rick Rediske
Annis Water Resources Institute
Grand Valley State University

Background on aquatic food web models

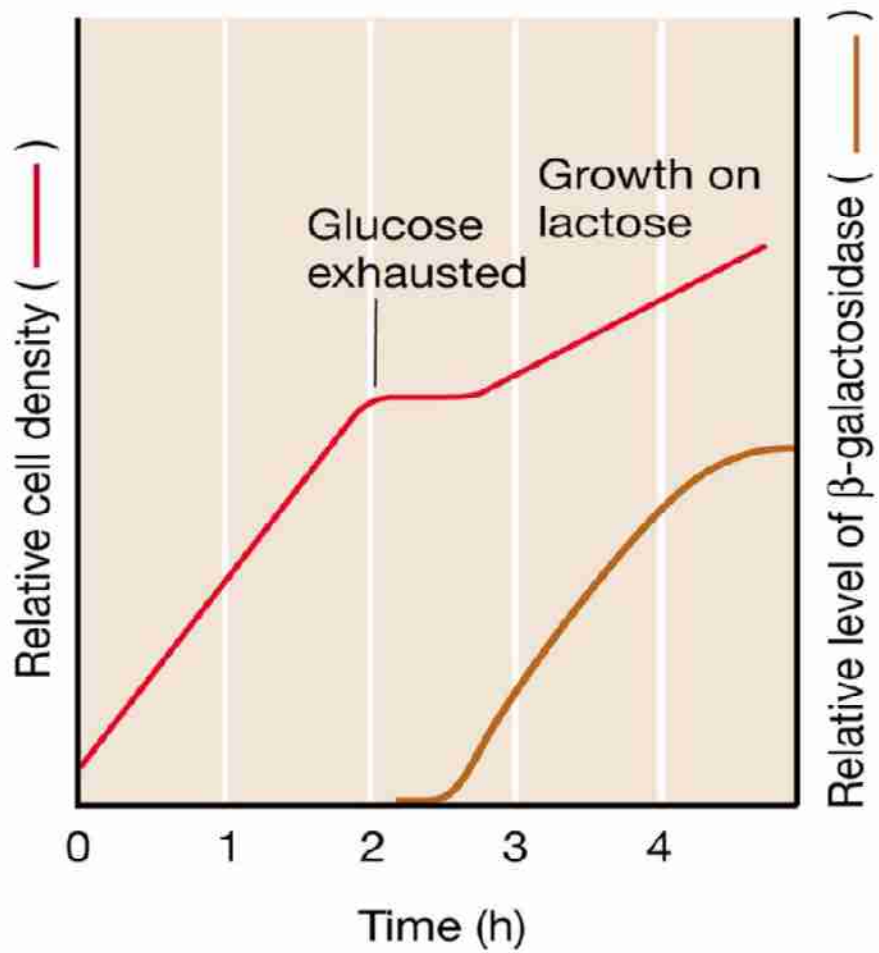
- Numerous models of freshwater and marine systems
- Studies commonly focus on C or N flow and represent compartments by C or N content
- No true stoichiometry (= molar ratios of reactants and products in a specified chemical reaction)

“Ecological stoichiometry” (Sterner & Elser)

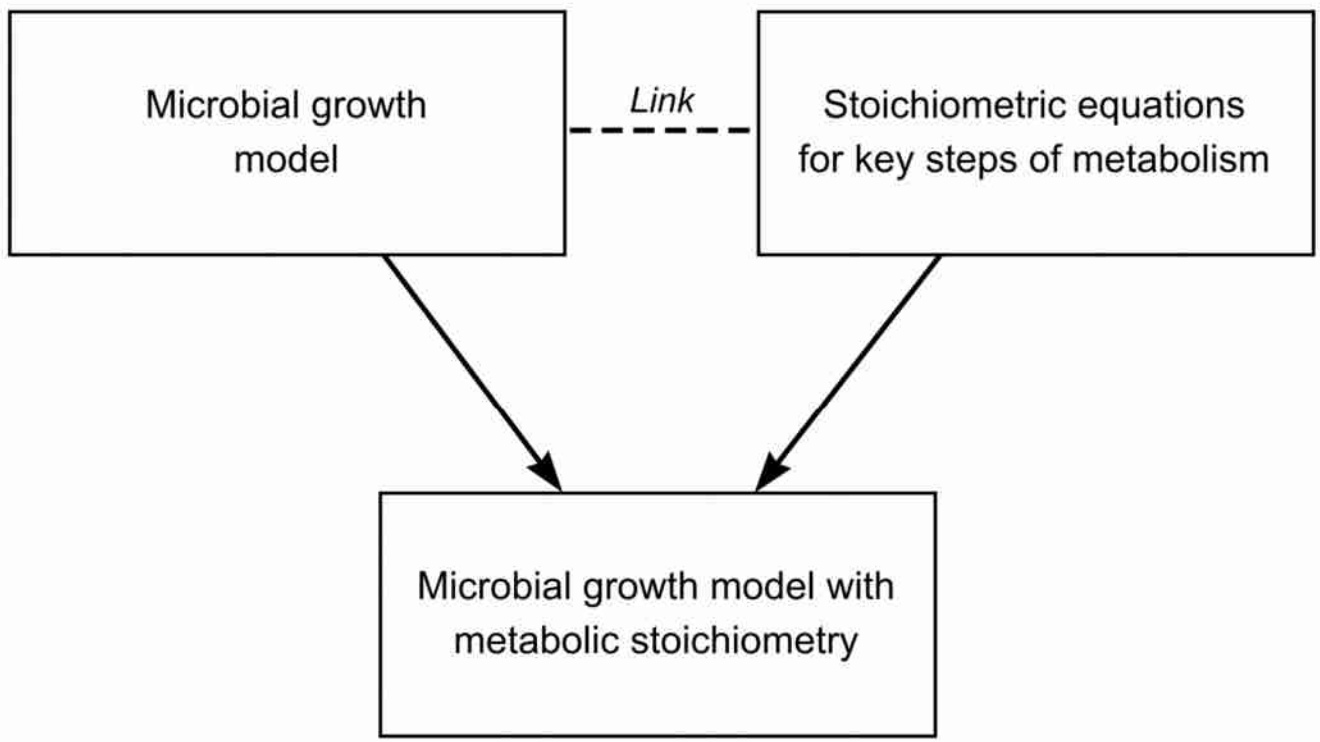
To date, really about *element ratios* in different organisms instead of relative quantities of reactants and products in specified reactions

The *context* of an element matters

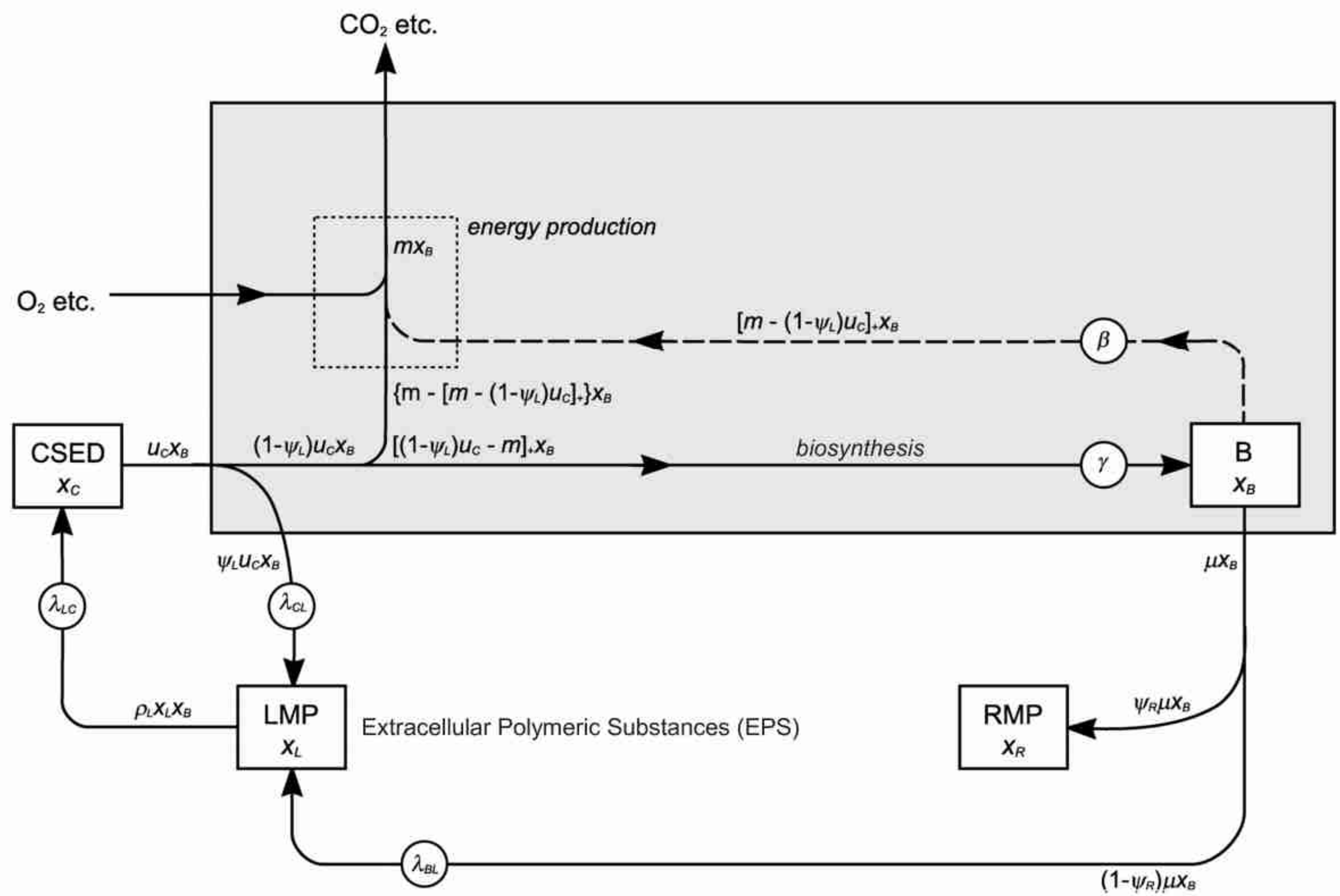
C-limited diauxic growth of *E. coli*



Basic idea of our approach



Flow diagram for basic heterotroph model



Basic heterotroph growth model

$$
\boxed{
\begin{aligned}
\frac{\mathrm{d}x_B}{\mathrm{d}t} &= Y_0 \cdot [(1-\psi_L)u_C - m]_+ \, x_B - b \cdot [m - (1-\psi_L)u_C]_+ \, x_B - \mu x_B \\
\frac{\mathrm{d}x_R}{\mathrm{d}t} &= \psi_R \mu x_B \\
\frac{\mathrm{d}x_L}{\mathrm{d}t} &= \psi_L u_C x_B + (1-\psi_R)\mu x_B - \gamma k x_L \\
\frac{\mathrm{d}x_C}{\mathrm{d}t} &= -u_C x_B + \gamma k x_L,
\end{aligned}
}
$$

Specific uptake rate:

$$u_C(x_C) = \frac{u_{\mathrm{sup}}\, x_C}{k_h + x_C}$$

Net biosynthetic yield:

$$Y_1 = \frac{Y_0 \cdot [(1-\psi_L)u_C - m]_+ \, x_B}{(1-\psi_L)u_C x_B} = Y_0 \cdot \left[1 - \frac{m}{(1-\psi_L)u_C}\right]_+$$

Reaction stoichiometry

Energy equation:

$$-R_{ed}: \quad \frac{1}{24}\mathrm{C_6H_{12}O_6} + \frac{1}{4}\mathrm{H_20} \rightarrow \frac{1}{4}\mathrm{CO_2} + \mathrm{H^+} + \mathrm{e^-}$$

$$R_{ea}: \quad \frac{1}{4}\mathrm{O_2} + \mathrm{H^+} + \mathrm{e^-} \rightarrow \frac{1}{2}\mathrm{H_2O}$$

$$R_e: \quad \underbrace{\frac{1}{24}\mathrm{C_6H_{12}O_6}}_{\text{CSED}} + \frac{1}{4}\mathrm{O_2} \rightarrow \frac{1}{4}\mathrm{CO_2} + \frac{1}{4}\mathrm{H_2O}.$$

Synthesis equation:

$$-R_{sd}: \quad \frac{1}{24}\mathrm{C_6H_{12}O_6} + \frac{1}{4}\mathrm{H_20} \rightarrow \frac{1}{4}\mathrm{CO_2} + \mathrm{H^+} + \mathrm{e^-}$$

$$R_{sa}: \quad \frac{1}{5}\mathrm{CO_2} + \frac{1}{20}\mathrm{HCO_3^-} + \frac{1}{20}\mathrm{NH_4^+} + \mathrm{H^+} + \mathrm{e^-} \rightarrow \frac{1}{20}\mathrm{C_5H_7O_2N} + \frac{9}{20}\mathrm{H_2O}$$

$$R_s: \quad \frac{1}{24}\mathrm{C_6H_{12}O_6} + \frac{1}{20}\mathrm{HCO_3^-} + \frac{1}{20}\mathrm{NH_4^+} \rightarrow \underbrace{\frac{1}{20}\mathrm{C_5H_7O_2N}}_{\text{Biomass}} + \frac{1}{20}\mathrm{CO_2} + \frac{1}{5}\mathrm{H_2O}.$$

Reaction stoichiometry

Overall equation:

$$\boxed{R = (1 - f_s)\, R_e + f_s\, R_s.}$$

$$\begin{aligned}
(1-f_s)R_e: \quad & \frac{1}{24}(1-f_s)C_6H_{12}O_6 + \frac{1}{4}(1-f_s)O_2 \rightarrow \frac{1}{4}(1-f_s)CO_2 + \frac{1}{4}(1-f_s)H_2O \\
f_s R_s: \quad & \frac{1}{24} f_s C_6H_{12}O_6 + \frac{1}{20} f_s HCO_3^- + \frac{1}{20} f_s NH_4^+ \rightarrow \frac{1}{20} f_s C_5H_7O_2N + \frac{1}{20} f_s CO_2 + \frac{1}{5} f_s H_2O \\
R: \quad & \frac{1}{24} C_6H_{12}O_6 + \frac{1}{4}(1-f_s)\, O_2 + \frac{1}{20} f_s\, HCO_3^- + \frac{1}{20}\, f_s\, NH_4^+ \rightarrow + \frac{1}{20} f_s\, C_5H_7O_2N + \\
& (\frac{1}{4} - \frac{1}{5}\, f_s)\, CO_2 + (\frac{1}{4} - \frac{1}{20}\, f_s)\, H_2O.
\end{aligned}$$

Or after simplifying:

$$\begin{aligned}
R: \quad & \underbrace{5\, C_6H_{12}O_6}_{\text{CSED}} + 30\,(1-f_s)\, O_2 + 6\, f_s\, HCO_3^- + 6\, f_s\, NH_4^+ \rightarrow \\
& (30 - 24\, f_s)\, CO_2 + (30 - 6\, f_s)\, H_2O + 6\, f_s\, \underbrace{C_5H_7O_2N}_{\text{Biomass}}.
\end{aligned}$$

Allocation fraction

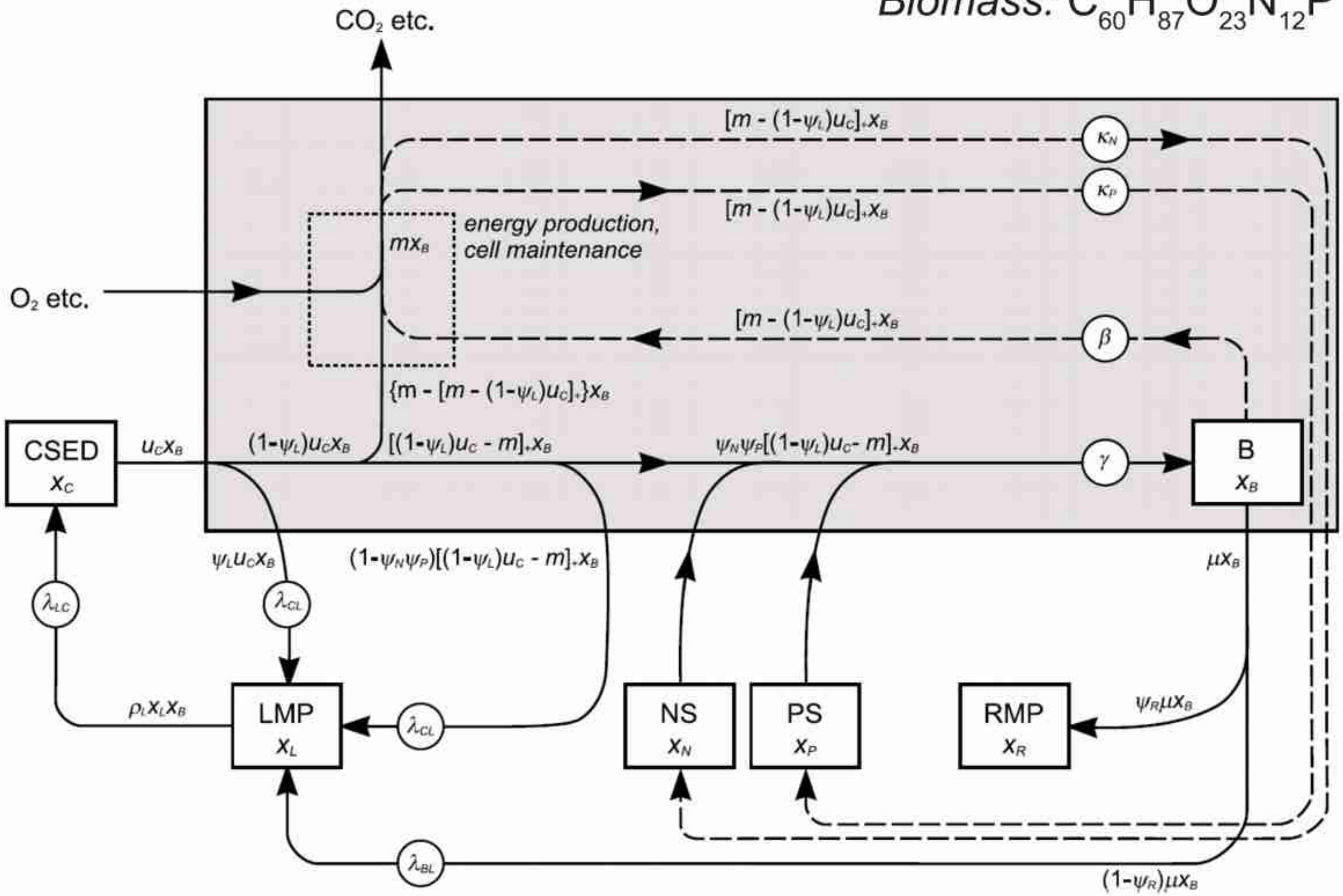
$$f_s = \frac{\frac{\text{mass CSED}}{\text{mole CSED}} \cdot \frac{\text{moles CSED consumed}}{\text{mole e}^- \text{ donated by CSED}}}{\frac{\text{mass biomass}}{\text{mole biomass}} \cdot \frac{\text{moles biomass synthesized}}{\text{mole e}^- \text{ committed to biomass}}} \cdot Y_1$$

$$= \frac{(180.1554)(0.0417)}{(113.1143)(0.0500)} \cdot Y_1 = 1.328 \cdot Y_1.$$

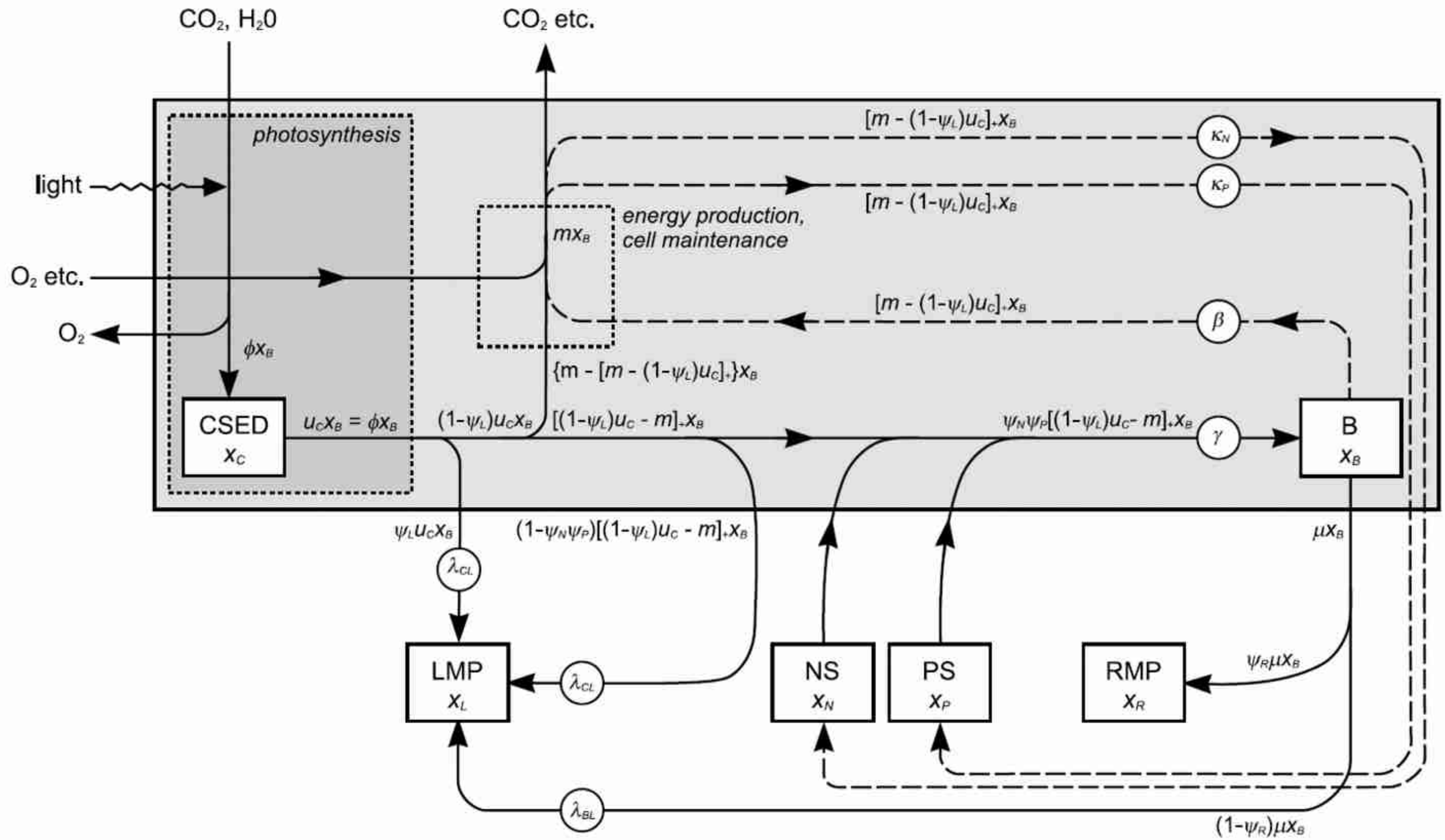
link to microbial growth model

Multiple potentially-limiting substrates

Biomass: $C_{60}H_{87}O_{23}N_{12}P$



Aerobic growth of oxygenic photosynthetic bacteria



Thank you

PBTs in Muskegon Lake

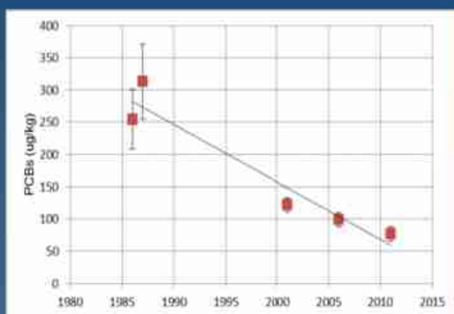
Richard Rediske
James McNair

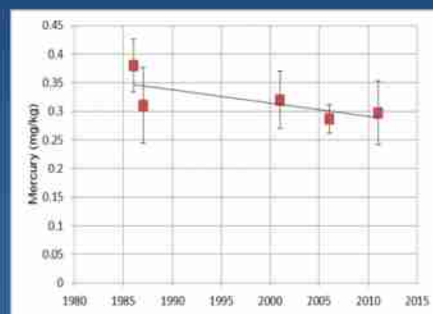
PBTs in Muskegon Lake

- PCBs and Mercury for AOC Delisting
- Assessment of Polybrominated Diphenyl Ethers in Michigan Fish from Several Trophic Levels

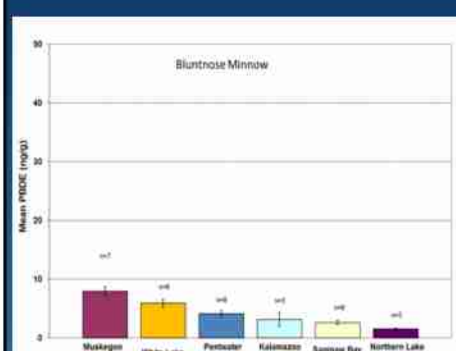
PCBs and Mercury in Carp

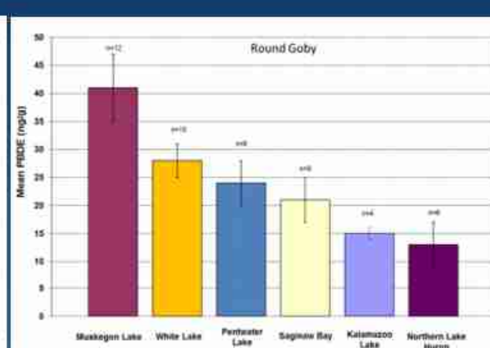
- PCBs show a decreasing trend
- Mercury levels have not changed



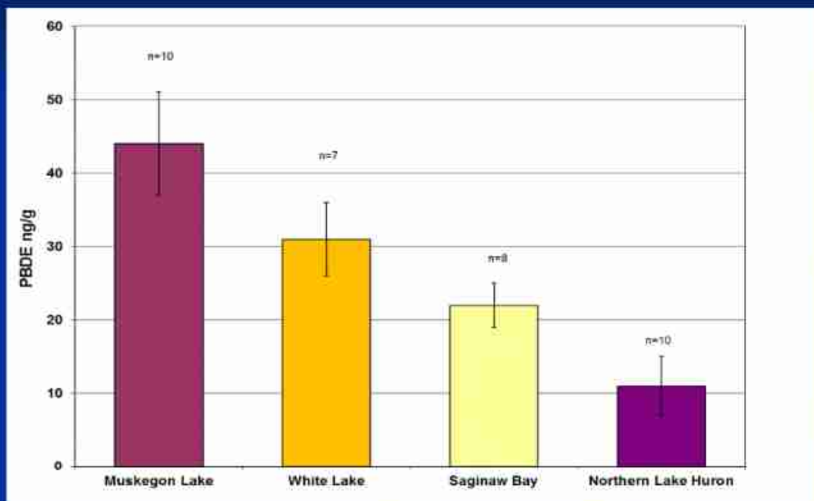


PBDE In Forage Fish





PBDE in Walleye



Fish bioaccumulation and bioenergetics model

- Mainly aimed at fish
- Mainly targets lipophilic organics
- Developing 2 versions:
  - Exploratory version (students, agency staff)
  - Research version
- Main sources:
  - Ng et al. (2008)
  - Arnot & Gobas (2004)
  - Munch & Conover (2002)
  - Wisconsin Fish Bioenergetics Model
  - Terrestrial vertebrate models (e.g., Dunham, O'Connor)
- Needs input from hard-core fish physiologist

Overview of structure

Contaminant mass:

$$\frac{dM}{dt} = \Big(\underbrace{\epsilon_W\, g_V(t)\, C_W(t)}_{\text{uptake from water}} + \underbrace{\epsilon_D\, g_D(t) \sum_i p_i(t)\, C_{D,i}(t)}_{\text{uptake from food}} \Big) B(t) - \Big(\underbrace{\epsilon_W\, g_V(t)/K_{BW}}_{\text{loss across gills}} + \underbrace{\epsilon_D\, g_F(t)\, K_{GB}}_{\text{egestion, excretion}} + \underbrace{g_E(t)}_{\text{egg transfer}} + \underbrace{k_M}_{\text{transformation}} \Big) M(t)$$

Contaminant conc.:

$$\frac{dC}{dt} = \underbrace{\epsilon_W\, g_V(t)\, C_W(t)}_{\text{uptake from water}} + \underbrace{\epsilon_D\, g_D(t) \sum_i p_i(t)\, C_{D,i}(t)}_{\text{uptake from food}} - \Big(\underbrace{\epsilon_W\, g_V(t)/K_{BW}}_{\text{loss across gills}} + \underbrace{\epsilon_D\, g_F(t)\, K_{GB}}_{\text{egestion, excretion}} + \underbrace{g_E(t)}_{\text{egg transfer}} + \underbrace{k_M}_{\text{transformation}} + \underbrace{\frac{1}{B}\frac{dB}{dt}}_{\text{growth dilution}} \Big) C(t)$$

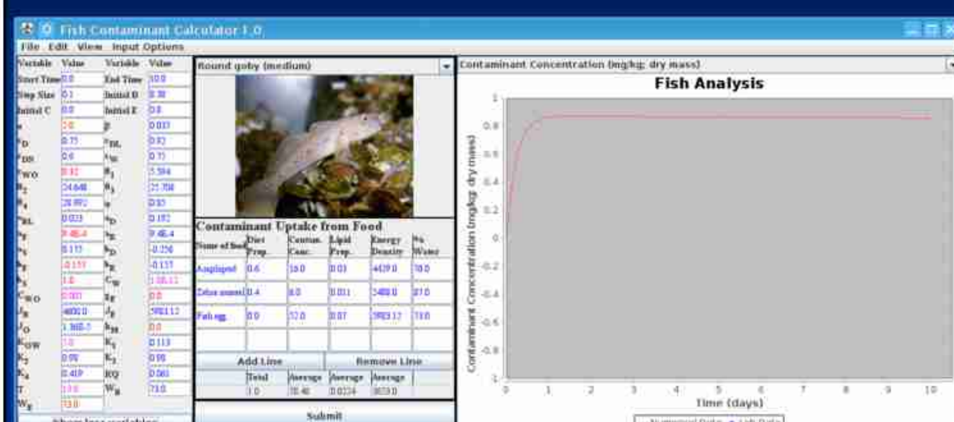
Fish mass:

$$\frac{dB}{dt} = \Big(\underbrace{\frac{J_D}{J_B}\,\varphi\, g_D(t)}_{\text{feeding}} - \underbrace{\frac{J_O}{J_B}\, s(t)}_{\text{SDA}} - \underbrace{g_E(t)}_{\text{egg transfer}} \Big) B(t) - \underbrace{\frac{J_O}{J_B}\,\alpha\, r(t)\,[B(t) + E(t)]}_{\text{respiration}}$$

Egg mass:

$$\frac{dE}{dt} = \underbrace{\frac{J_B}{J_E}\, g_E(t)\, B(t)}_{\text{maternal transfer}} - \underbrace{\frac{J_O}{J_E}\, r_E(t)\, E(t)}_{\text{respiration}}$$

Exploratory program user interface



Next Steps

- How does watershed size influence PBDE concentration?
- How does food web structure influence PBT bioaccumulation?
- PBTs in altered food webs in Saginaw Bay and Lake Erie

Carbon Cycle, Lake Observatory and Sinkhole Science in the Great Lakes: Insights from Time-Series Data

"The song of the water is audible to every ear.
but there is other music in these hills,
by no means audible to all.
To hear even a few notes of it you must first
live here for a long time,
and you must know the speech of hills and rivers."

– Aldo Leopold (Song of the Gavilian, 1940).

Bopi Biddanda, Annis Water Resources Institute, GVSU

Great Lakes Connectivity Workshop

GLERL and GVSU – April 28, 2014

GRAND VALLEY STATE UNIVERSITY
ROBERT B. ANNIS WATER RESOURCES INSTITUTE

GLERL

Lab Projects/Goals:

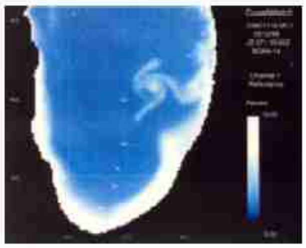
1. Understand Carbon flow In Lake Michigan and its Watersheds

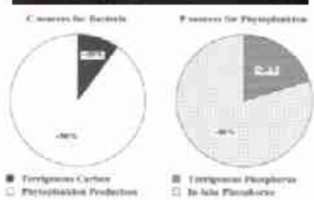
2. Explore Submerged Sinkhole Ecosystems in Lake Huron

3. Develop a Time-series Observatory for Muskegon Lake AOC

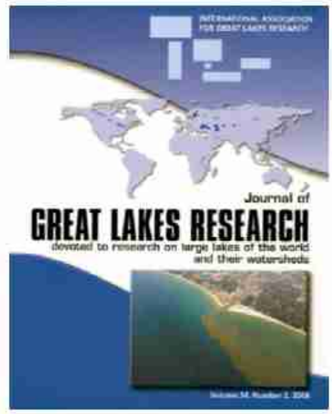
1. Carbon Cycling

Carbon and Nutrient Cycling in Lake Michigan: Though the lake is huge, it is closely connected to its watershed



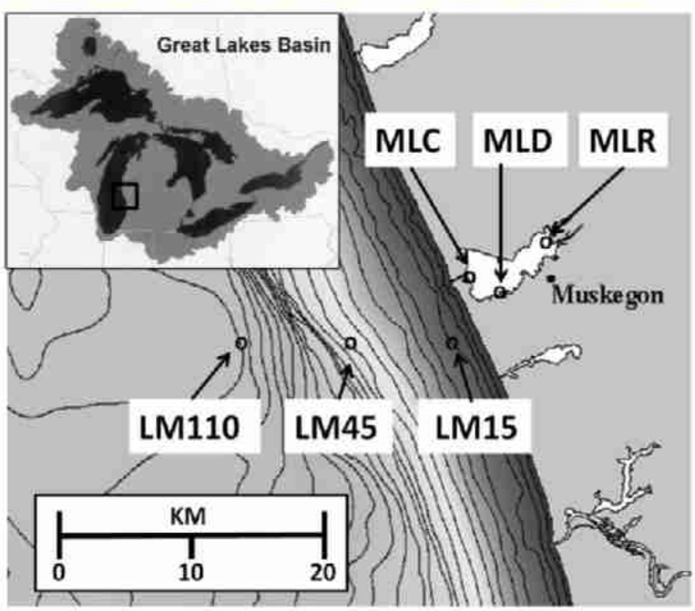


EEGLE 1998-2002

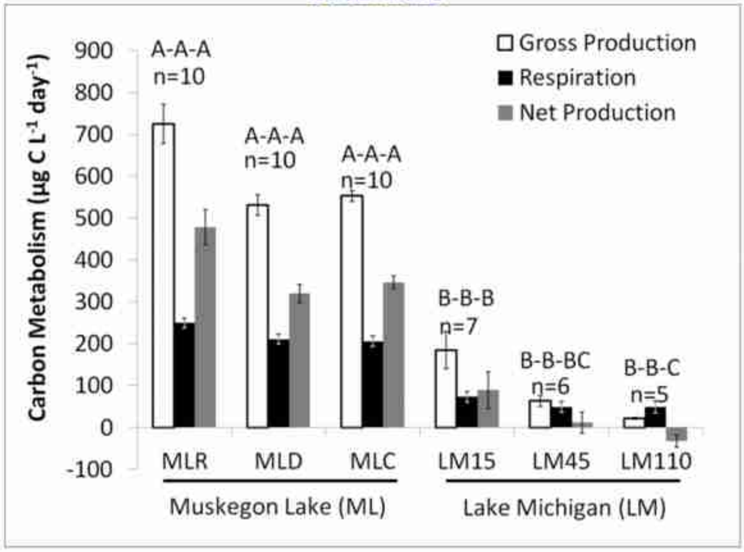


Biddanda and Cotner, Ecosystems 2002
Johengen et al, J. Great Lakes Res 2008

Land to Lake Plankton Metabolism: Lake Michigan Transect Study 2002-2013

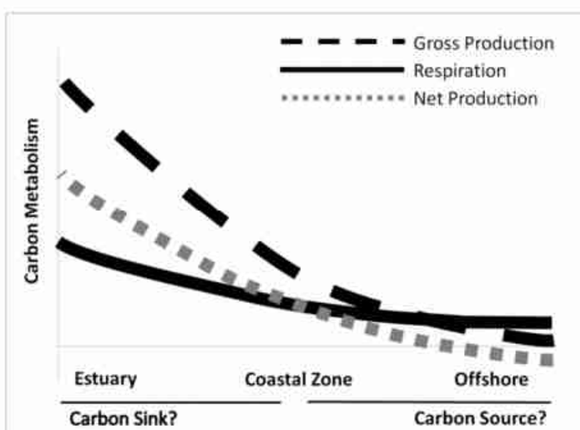


Schematically Variable Carbon Cycling along Land to Lake Gradient 2002-2013



Weinke et al. (J. Plankton Research; In Review)

Schematic Model of Variable Carbon Cycling along Land to Lake Gradient



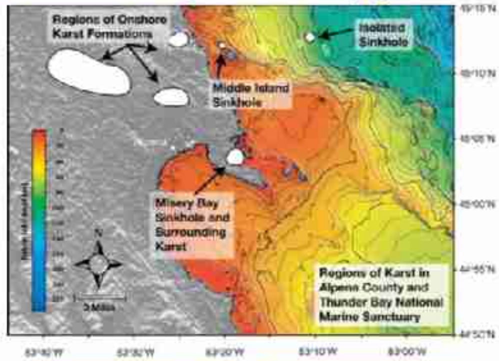
Nearshore Net C production

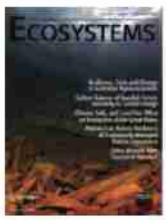
Net C respiration offshore

Q: Does this trend hold for all of the Great Lakes?

2. Exploring Sinkhole Ecosystems

Submerged Karstic Sinkholes in Lake Huron are bathed in groundwater rich in Sulfur and poor in Oxygen

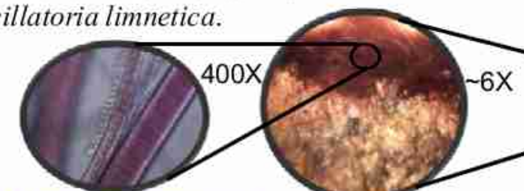




Ruberg et al MTJS 2005, 2007; Biddanda et al. Ecosystems 2006; Eos 2009.

Sinkhole Cyanobacterial Mats - Microbes Only!

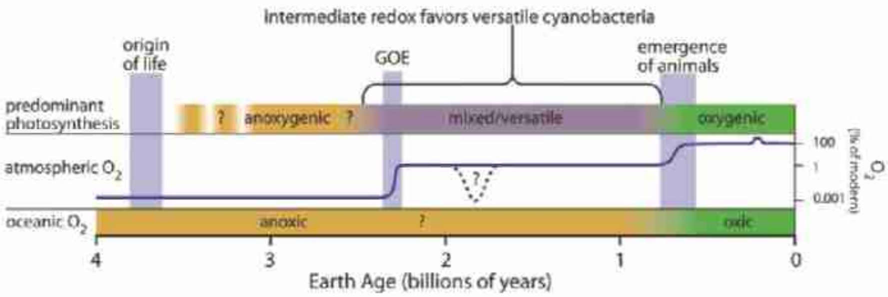
- Low biodiversity – dominated by *Phormidium autumnalae* and *Oscillatoria limnetica.*



- High functional versatility – Anoxygenic and Oxygenic photosynthesis

Voorhies et al 2013 Geobiology

Life in a Low Oxygen-high Sulfur Lake Huron Sinkhole:
Cyanobacterial mats – Modern analogs of Early Earth Biota?



Biddanda et al. 2012 Nature Education Knowledge

Where else on Earth are similar mat communities found?

Dale T. Andersen
images.spaceref.com/astro/llar/sm0207.JPG

Lake Hoare, Antarctic Dry Valley

Q1: Are there submerged sinkholes in other Lower Great Lakes?
Q2: What can we learn about oxygenation, carbon burial and life?
Q3: Are these unique simple/versatile communities worth conserving?

2. Lake Observatory

Muskegon Lake Observatory

www.gvsu.edu/buoy

1. Is a continuous time-series monitoring system to measure biological, chemical and physical characteristics.

2. *Links data to regional/global observatory networks*

3. Enables research, training, education and outreach

data.glos.us/portal/

Muskegon Lake Observatory 2010-2014:

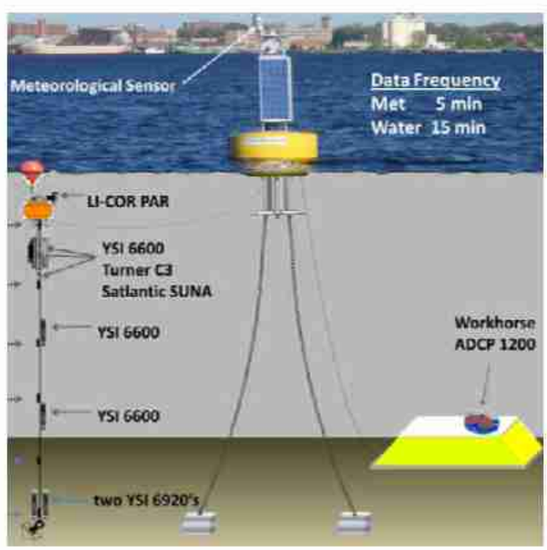
EPA funded – GLRI

- 2010-2013; → 2014

Focus Areas:

•Support AOC monitoring and delisting
•Water Column Features
•Chlorophyll & HABs
•O & C Cycling*
•Hypolimnetic Hypoxia
•Hydrodynamics**

** McNair talk this afternoon*
*** Kendall talk tomorrow*



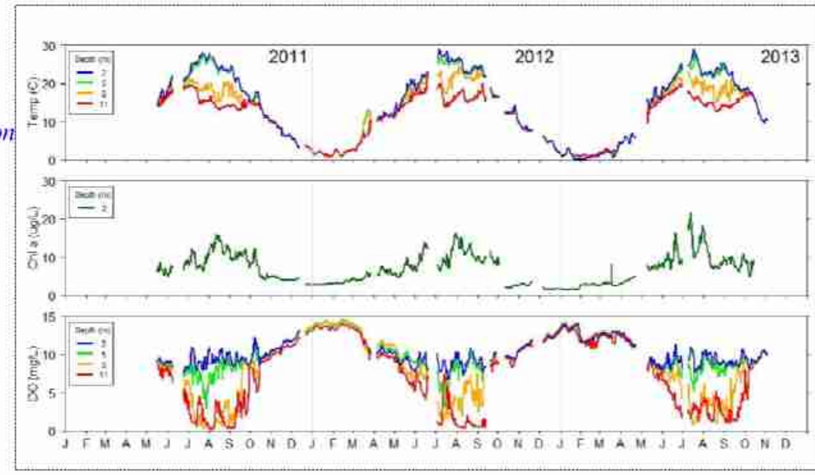
POWER OF RELIABLE TIME-SERIES ECOSYSTEM DATA:

Track

Lake Stratification

Biomass Production

Evolution of Hypoxia



- ***Each year about of the lake experiences hypoxia for ~45 days.***

Biddanda and Kendall (in prep).

Tale of Two Summers: Similar Chlorophyll but Very Different HABs

Gereaux et al. (in prep)

Summer 2011 | **Summer 2012**

Chlorophyll *a* (ug/L)

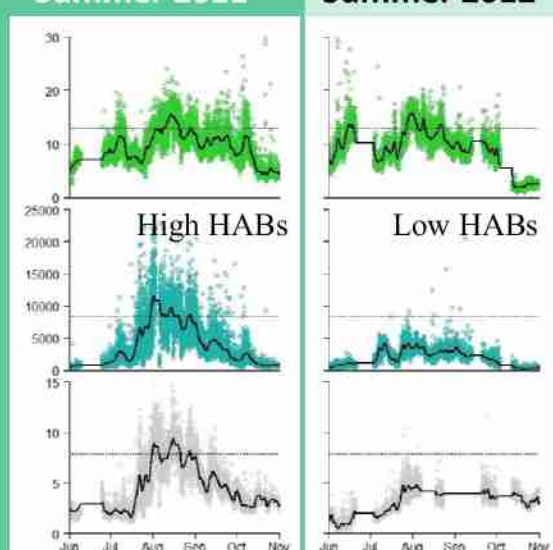
- *Approx equal between years*

Phycocyanin (cells/ml)

- *~ 2X higher summer 2011*

Turbidity (NTU)

- *~ 2X higher summer 2011*



WET | DRY

Emerging Questions for Ecosystem Change Studies in the Great Lakes

Q1: Over what relevant time and space scales should we study ecosystem change?

Q2: How do we sustain long-term research to encompass the time and space scales relevant to the inventories and processes that are undergoing change?

<u>Tomorrow Morning</u>: Scott Kendall will have more on the Observatory findings on Hydrodynamics of Muskegon Lake and our plans for coastal Lake Michigan

Acknowledgement of Support:

NSF

Grand Valley State University
Robert B. Annis Water Resources Institute

Michigan Space Grant Consortium

United States Environmental Protection Agency

NOAA
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

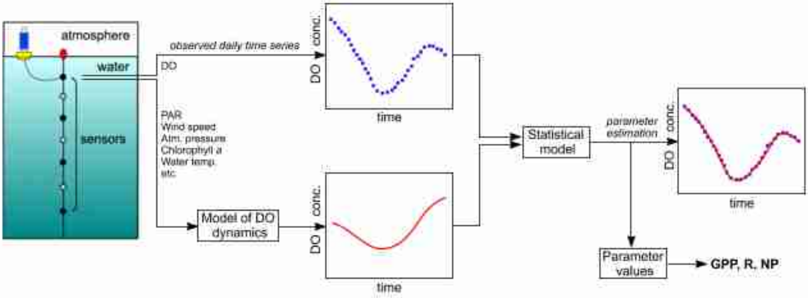
New approaches for estimating components of lake metabolism by the free-water dissolved-oxygen method

James McNair, Meagan Sesselmann, Leon Gereaux, Anthony Weinke, Scott Kendall, and Bopaiah Biddanda

Annis Water Resources Institute
Grand Valley State University
Muskegon, Michigan

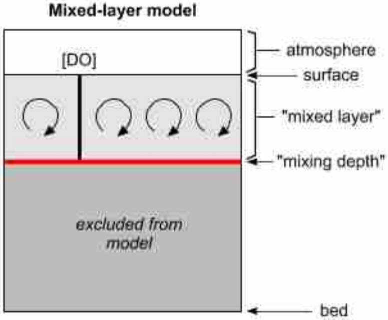
28 April 2014

Overview of the prediction-based free-water DO method



GPP: gross primary production
R: total aerobic respiration
NP: net production = GPP − R

How mixed-layer models conceptualize a lake



Basic mixed-layer modeling framework

$$\frac{dC}{dt} = \overbrace{-\rho'(t)}^{respiration} + \overbrace{\gamma(t)}^{atm.\ exchange} \qquad \text{(nighttime)}$$

$$\frac{dC}{dt} = \underbrace{\pi(t)}_{photosynthesis} - \underbrace{\rho(t)}_{respiration} + \underbrace{\gamma(t)}_{atm.\ exchange} \qquad \text{(daytime)}$$

Alternative choices of rate functions

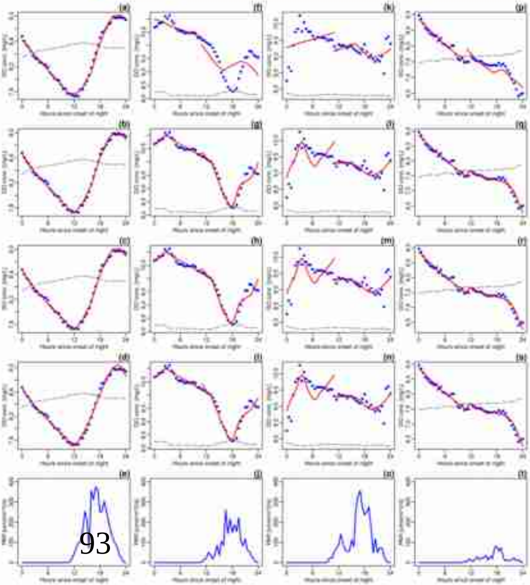
$\pi(t)$	$\rho(t)$	$\gamma(t)$
(a) Forms from Hanson et al. (2008):		
$\psi p(t)$	ρ_0	$k(t)[C_s(t) - y(t)]/Z(t)$
$p^* \left(1 - e^{-\psi p(t)/p^*}\right)$	$\rho_0 + \rho_1 p(t)$	
	$\rho_0 + \rho_1 \sum_{\tau=0}^{t} e^{-\rho_2 \tau} p(t-\tau)$	
(b) Forms from McNair et al. (2013):		
$\psi p(t)$	$\begin{cases} \rho' & \text{(nighttime)} \\ \rho & \text{(daytime)} \end{cases}$	$k(t)[C_s(t) - C(t)]/Z(t)$
		$k(t)[C_s(t) - y(t)]/Z(t)$
		$\beta\, k(t)[C_s(t) - y(t)]/Z(t)$
(c) New forms from this paper:		
$\psi p(t)$	$\begin{cases} \rho_0' & \text{(nighttime)} \\ \rho_0 & \text{(daytime)} \end{cases}$	$k(t)[C_s(t) - y(t)]/Z(t)$
$\psi \chi(t) p(t)$	$\begin{cases} \rho_0' + \rho_1'[\chi(t) - \bar{\chi}] \\ \rho_0 + \rho_1[\chi(t) - \bar{\chi}] \end{cases}$	$\beta\, k(t)[C_s(t) - C(t)]/Z(t)$
$\psi \chi(t)(1+\epsilon_\pi)^{\Theta(t)-20} p(t)$	$\begin{cases} (\rho_0' + \rho_1'[\chi(t) - \bar{\chi}])(1+\epsilon_\rho)^{\Theta(t)-20} \\ (\rho_0 + \rho_1[\chi(t) - \bar{\chi}])(1+\epsilon_\rho)^{\Theta(t)-20} \end{cases}$	
$\psi \chi(t)(1+\epsilon_\pi)^{\Theta(t)-20} \frac{p(t)}{p^*} e^{1-\frac{p(t)}{p^*}}$		

"Vanilla" mixed-layer model

Add chlorophyll a as a predictor

Add temperature dependence

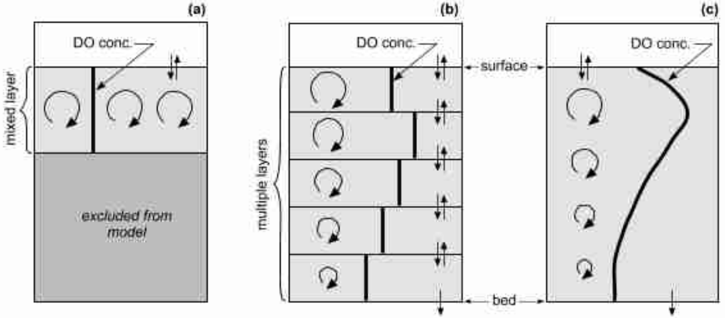
Add light inhibition



Summary of findings to date

- Regardless of how the production and consumption terms of the model of DO dynamics are refined, for many days during 2011–2013:
  - The model fit is poor, or
  - Some of the parameter estimates are inappropriate/impossible
- *Conclusion:* at least one fundamental process is missing or inadequately represented in mixed-layer models of lake DO dynamics
- *Working hypothesis:* mixed-layer models do not adequately represent physical transport and mixing processes in Muskegon Lake.

Mixed-layer model versus practical alternatives



Related publications

McNair JN, Sesselmann MR, Gereaux LC, Weinke AD, Kendall ST, Biddanda BA. 2014. Alternative methods for estimating components of lake metabolism using process-based models of dissolved-oxygen dynamics. *Fundamental and Applied Limnology* (in review).

McNair JN, Gereaux LC, Weinke AD, Sesselmann MR, Kendall ST, Biddanda BA. 2013. New methods for estimating components of lake metabolism based on free-water dissolved-oxygen dynamics. *Ecological Modelling* **263**: 251–263.

Thank you

Grand Valley State University

Great Lakes Restoration Initiative

CSI Lake Erie: Investigating the ecology of CHABs and improving bloom forecasting using molecular techniques

Timothy Davis

CEGLHH

GLERL
Great Lakes Environmental Research Laboratory

NOAA

Source tracking potential microcystin-producing cyanobacteria throughout the Great Lakes

- Collaboration with George Bullerjahn and Mike McKay, Jan Ciborowski, Sue Watson
- Maumee and Sandusky Rivers are sources of nutrients and sediments but it appears a thought some
- Previous studies show that 5% of all sequences in a Lake Superior metagenome map to *Microcystis* (Bullerjahn, pers comm.)
- Previous studies used the same primers in Lake Erie and Lake Ontario studies (Rinta-Kanto et al., 2006, Hotto et al, 2007) so my results will be comparable to previous work.
- Manuscript in review at PLOS ONE

Photo: NASA

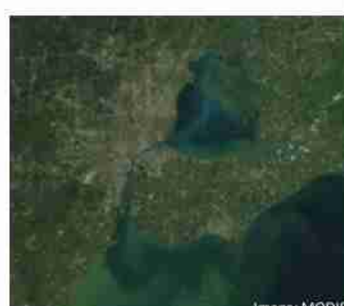


Image: MODIS

Multiplex qPCR: understanding competition among CHAB species in the Great Lakes

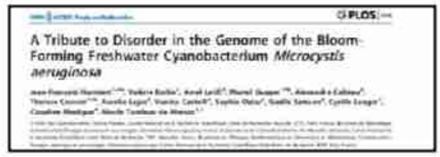
- This proposed work would be a continuation of my current grant
- In Lake Erie, cylindrospermopsin, anatoxin, and microcystin have been detected
- The specie(s) responsible for the production of CYN and ATX are currently unknown
  - CYN production: *Cylindrospermopsis* or *Aphanizomenon*?
- Would significantly enhance models aimed at predicating bloom toxicity
- Conducting mechanistic experiments that would help elucidate the competition between potential cyanotoxin producers

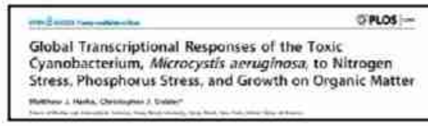
Elucidating ecological adaptions of Great Lakes CHAB species

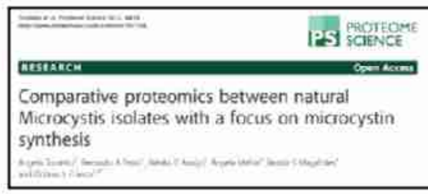
- *Microcystis* blooms (Western Basin Lake Erie, Lake St. Clair, Green Bay, Hamilton Harbor) *Anabanea* blooms (Cleveland area & Western Basin of LE, Bay of Quinte) and *Planktothrix* blooms in Sandusky Bay
- Isolation of Great Lake HAB species from major bloom-forming genera
- Controlled laboratory experiments investigating the competition between species under varying environmental conditions
- Further understating the interactive roles of light, nutrients, ROS and temperature on toxin production and community composition
- This would involve investigating the molecular response of these phytoplankton to different environmental variables (light, nutrient, temperature, CO_2, ROS) on a global level (comparative genomic/transcriptomic studies)

Genomics of Great Lakes CHAB species

- Very few Great Lake HAB genomes have been sequenced
- Understanding the global response of HAB species to environmental stressors
- Comparative genomics of toxic and non-toxic strains
- Laboratory and field experiments aimed at elucidating the transcriptomic response of individual strains and the overall community to changes in the physical and chemical environment
- Proposals funded by Ohio Sea Grant and CILER


A Tribute to Disorder in the Genome of the Bloom-Forming Freshwater Cyanobacterium *Microcystis aeruginosa*


Global Transcriptional Responses of the Toxic Cyanobacterium, *Microcystis aeruginosa*, to Nitrogen Stress, Phosphorus Stress, and Growth on Organic Matter



Comparative proteomics between natural Microcystis isolates with a focus on microcystin synthesis

Autonomous real-time qPCR for Great Lake moorings

- Already developed for marine HABs including *Pseudo-nitzschia* & *Synechococcus, Alexandrium*
- Environmental Sample Processor (ESP; Monterey Bay Aquarium Research Institute)
- Would be able to track blooms at a resolution that was previously unattainable with traditional sampling
- Can be referenced against physical, chemical and biological conditions
- Would be extremely valuable in the development of models
- Working with Greg Doucette (NOAA biotoxins) to develop an ELISA method for MC-LR
- qPCR technique with MBARI for *mcyA*

Photos: Monterey Bay Aquarium Research Institute

Development of an inexpensive and user-friendly DNA preservation method

- Collaboration with George Bullerjahn, Steve Giglio, Susan Watson
- 12 strains were pipetted onto duplicate FTA cards and allowed to dry at room temperature and left at 24° C or 37° C for ~2 weeks
- DNA was then extracted and purified

Strain	Toxic?
Anabaena variabilis NIVA 19	+ mcy
Synechococcus sp. ARC 11	-
Synechococcus sp. CP1181	-
Anabaena vigueri	-
Pseudanabaena sp. LE011-01	-
Planktothrix sp. LE011-012	-
Anabaena variabilis NIVA 19	+ mcy
Microcystis aeruginosa 15A	unknown
Anabaena planktonica	-
Anabaena sp. A102	-
Microcystis viridis NIVA169/9	+ mcy
Pseudanabaena limnetica NIVA 111	unknown

Implement the FTA card monitoring program

- Not possible to monitor all systems for HAB events
- Beach monitoring agencies, water management officials and citizen scientists
- Allow for spatial monitoring that would be impossible using other methods
- Gain a more comprehensive understanding of the spatial and temporal trends of potentially toxic blooms across Michigan and the Great Lakes region
- Manuscript in preparation

Other related work

- Investigating the nutrient response of winter diatom blooms in Lake Erie and potential links to an increasing hypoxic zone vs. increased zooplankton populations
- Investigating the influence of CO_2 on the growth rate of potentially toxic cyanobateria (manuscript in preparation)
  - Large swings in CO_2 occur over the course of a field season to we wanted to understand how these changes in CO_2 were impacting growth rates of potential toxin producing cyanobacteria
- DNA barcoding and metagenome project in Georgian Bay- Collaboration with the Biodiversity Institute of Ontario and University of Guelph.
- Benthic and pelagic grazing on Lake Winnipeg *Aphanizomenon* blooms
- *Microcystis* blooms in brackish waters of the Chesapeake Bay

Lake Michigan - Muskegon Lake Connectivity Workshop

HABs and Hypoxia Decision Support Tools

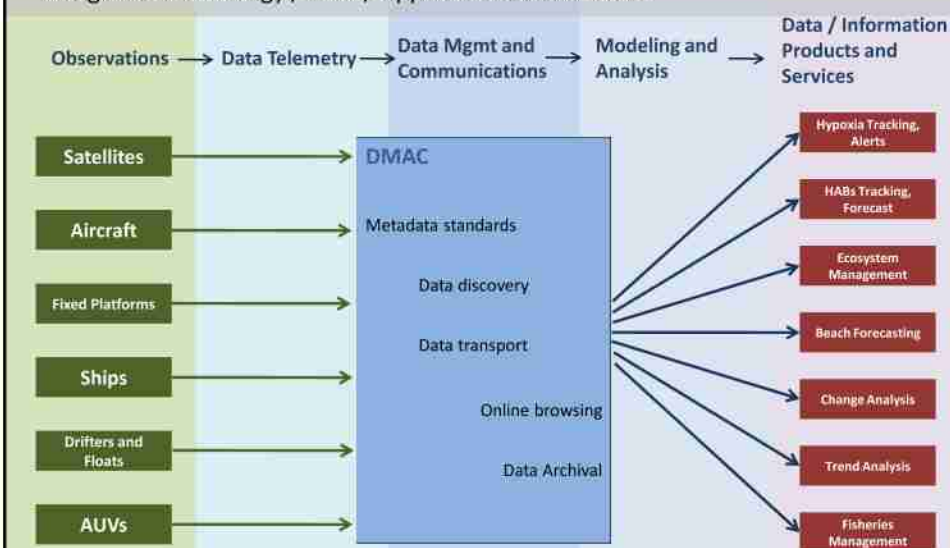
Developed under the GLRI Synthesis, Observations and Response (SOAR) project

April 28, 2014

GLERL

GLRI Synthesis Observations and Response (SOAR)

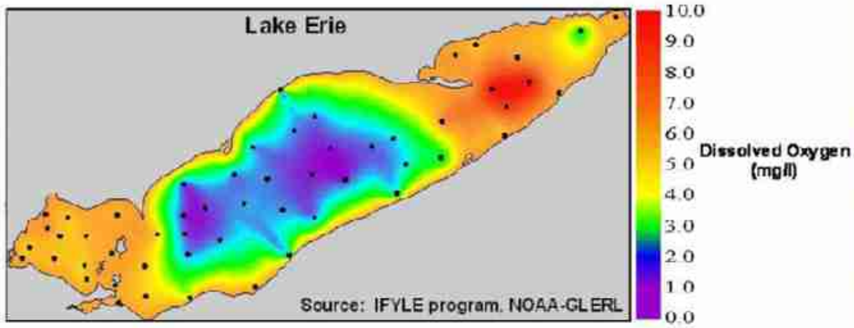
Integrated Technology / Data / Applications Architecture



Enterprise Architecture Framework

Technology Architecture → Data Architecture → Applications Architecture

Extent of Hypoxia in 2005

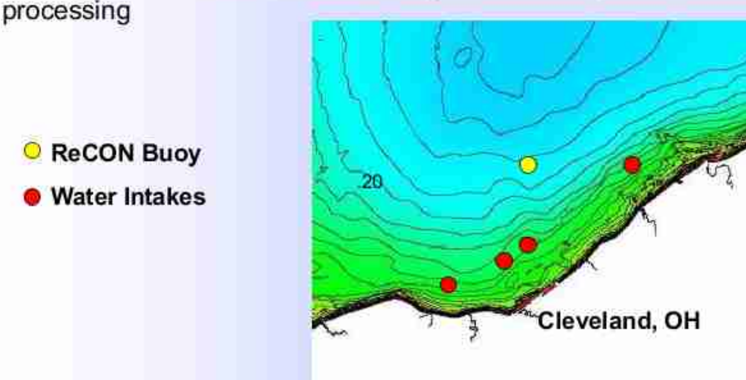


GLERL

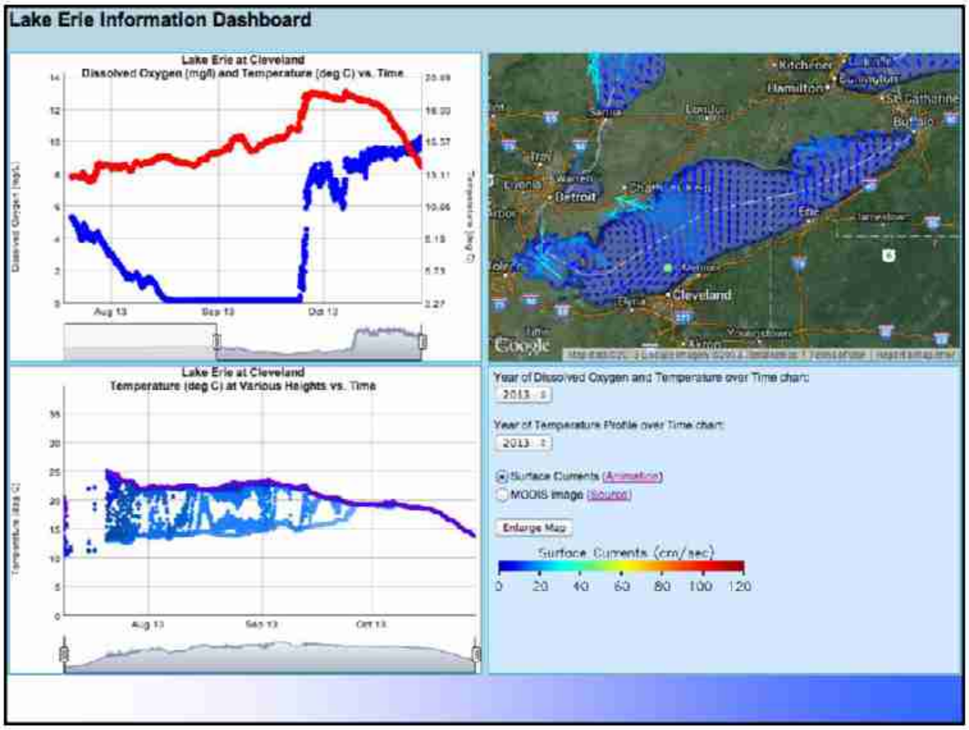
Hypoxia Warning System Project

Internal waves combined with hypoxic water can impact drinking water processing for about 2 million coastal residents

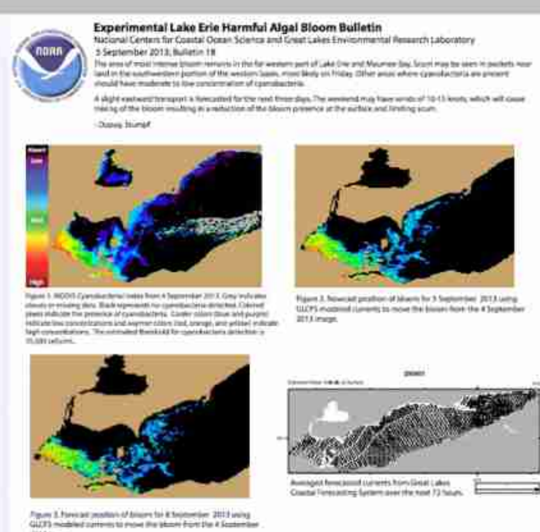
- real-time observations allow managers time to implement alternative processing



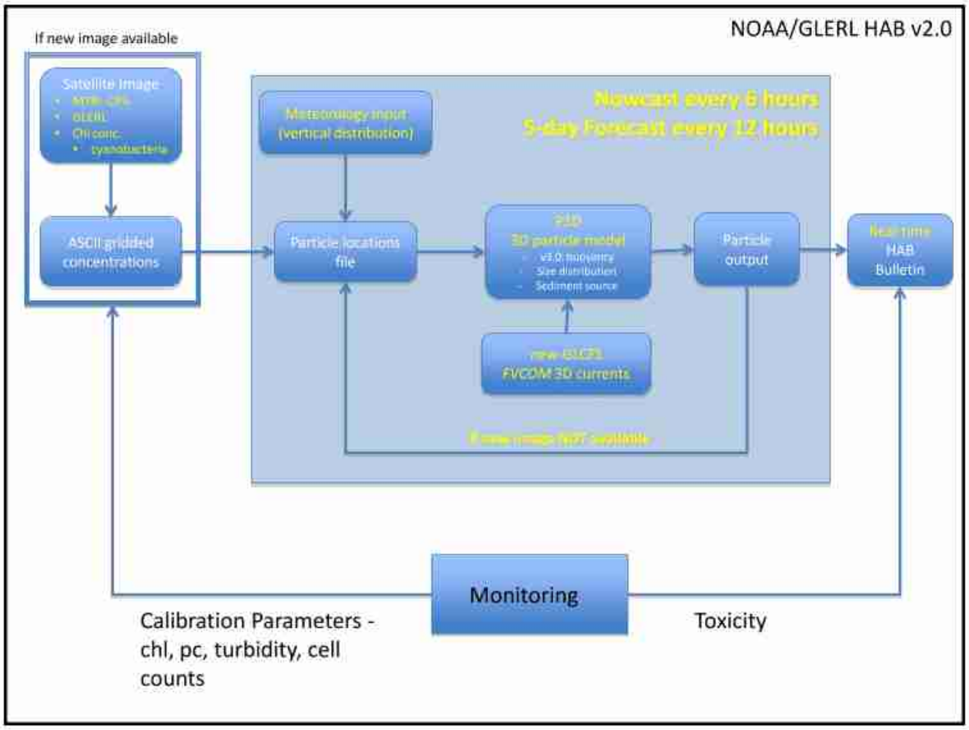
GLERL



Current HABs Bulletin



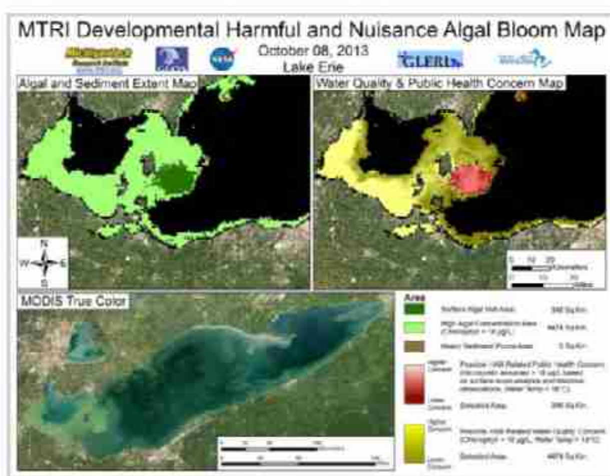
GLERL



2013 HABs Summary

2013 bloom was forecasted to be 20% of the 2011 bloom.

Average HAB extent in Western L. Erie Basin (derived from MODIS)	
2011	892 sq.km
2012	221 sq. km.
2013	676 sq. km



Location	Highest Observed Microcystin Levels	Date
Western L. Erie	56.4 ug/l	Aug.19
Saginaw Bay	3.5 ug/l	Sept. 3

8

4

Muskegon Lake HABS

Richard Rediske

Methods

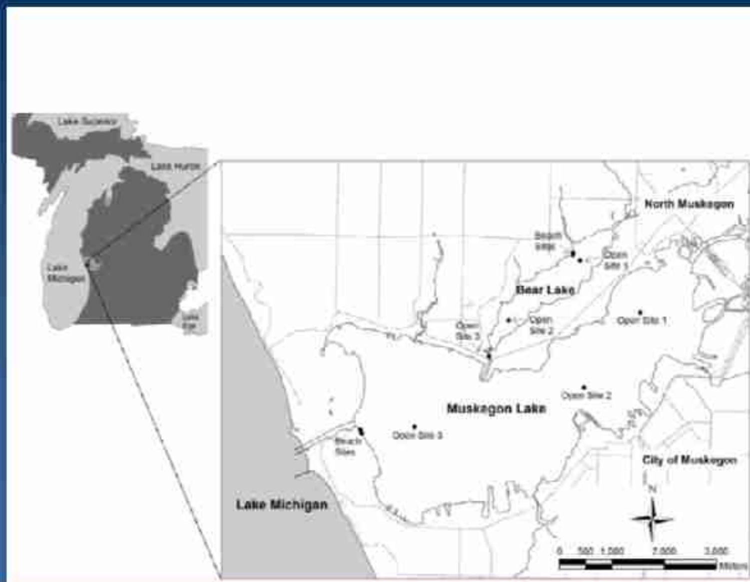
Field

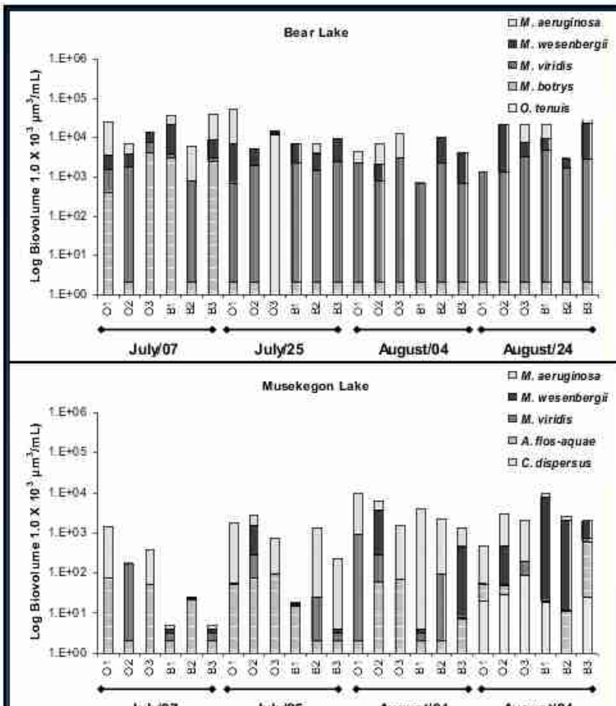
- Integrated 1 m water sample and surface (when present)
- 3 pelagic and 3 beach samples
- 2X in July and August

Laboratory

- Protein Phosphatase Inhibition (PPIA)
- HPLC/MS Microcystins LR, RR, LA, YR and Cylindrospermopsin
- Nutrients and limnological parameters
- Chlorophyll *a*
- Plankton Counts
- PCR analysis of the PKS gene

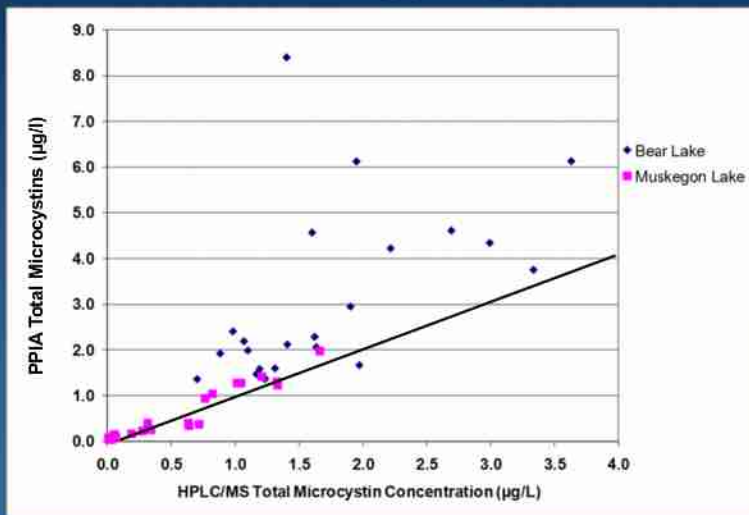
Sampling Locations



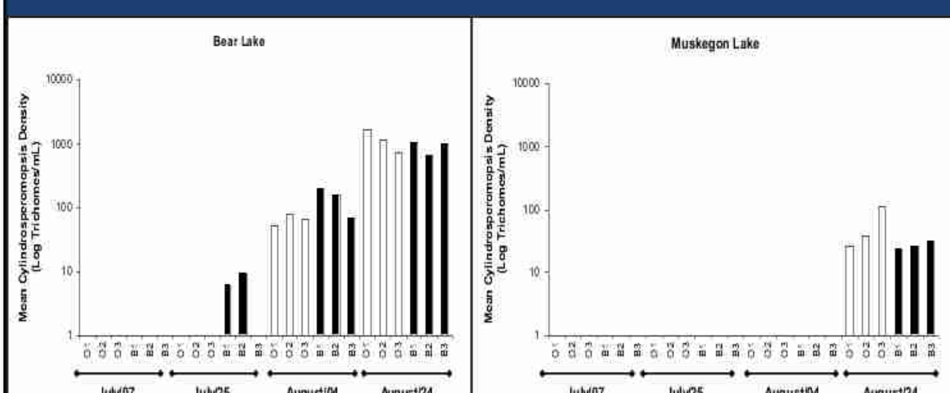


Cyanobacteria in Bear Lake and Muskegon Lake

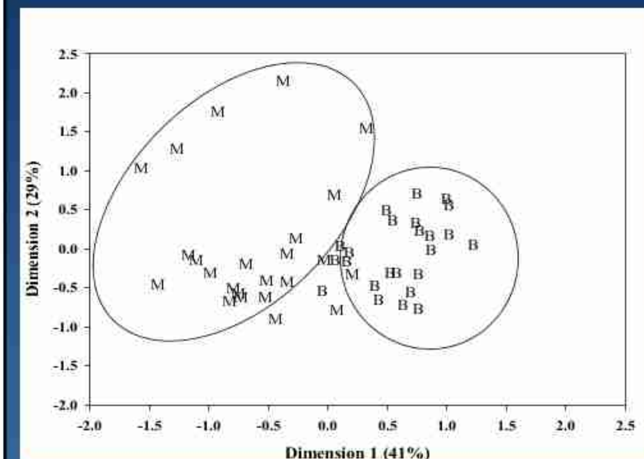
PPIA vs Total Microcystins by HPLC/MS



Cylindrospermopsis raciborskii in Bear Lake and Muskegon Lake (trichomes/ml)



NMDS ordination of cyanobacteria assemblages (35 taxa) sampled with 15 physical/chemical variables



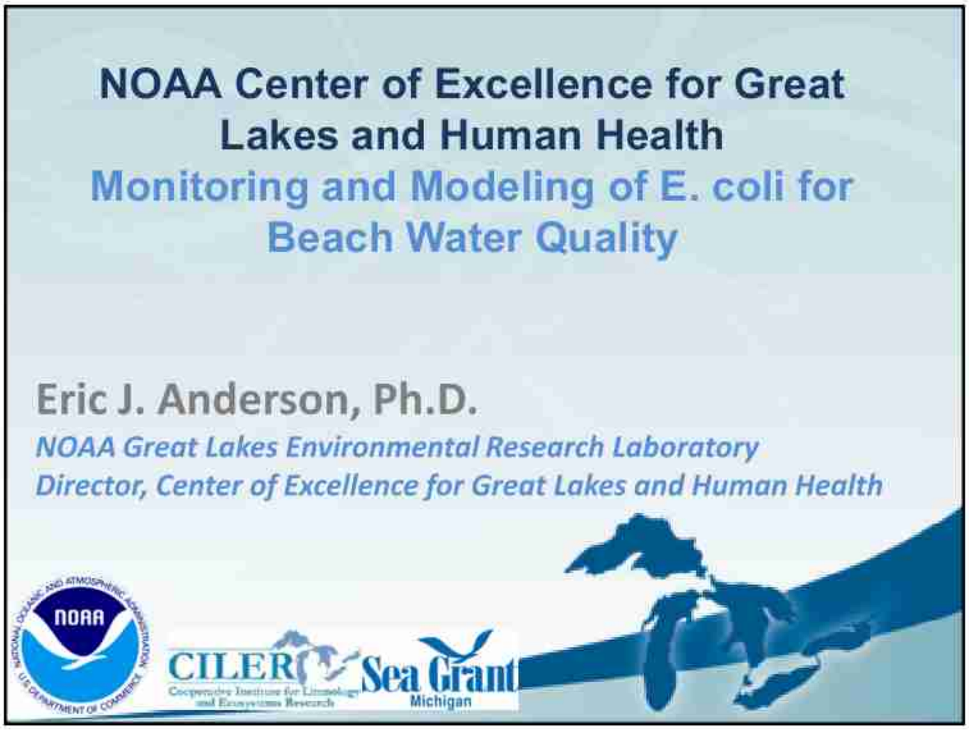
Spearman's rho Dimension 1 was significantly (correlated with turbidity (r=0.82), nitrate (r=-0.60), TP (r=0.59), total microcystin (r=0.61), MC-RR (r=0.76), and cyanobacteria biovolume (r=0.85).

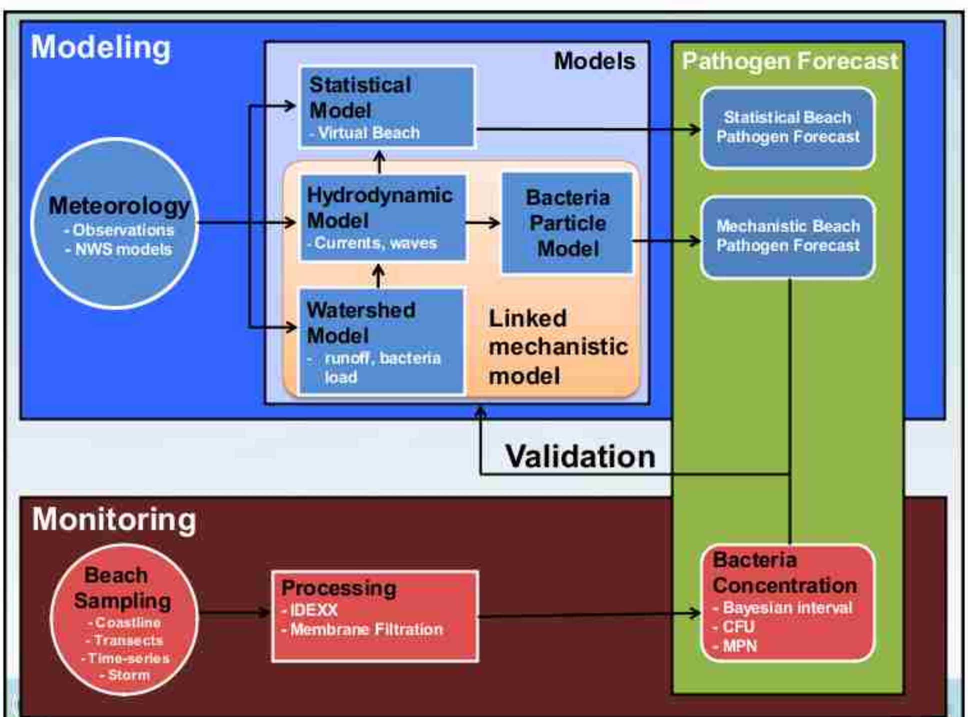
Cylindrospermopsis raciborskii

- *C. raciborskii* was positively correlated with turbidity (p=0.00)
- The strain was determined to be not capable of producing cylindrospermopsin due to the absence of the PKS gene
- Bear Lake appears to be the source of *C. raciborskii* in Muskegon Lake

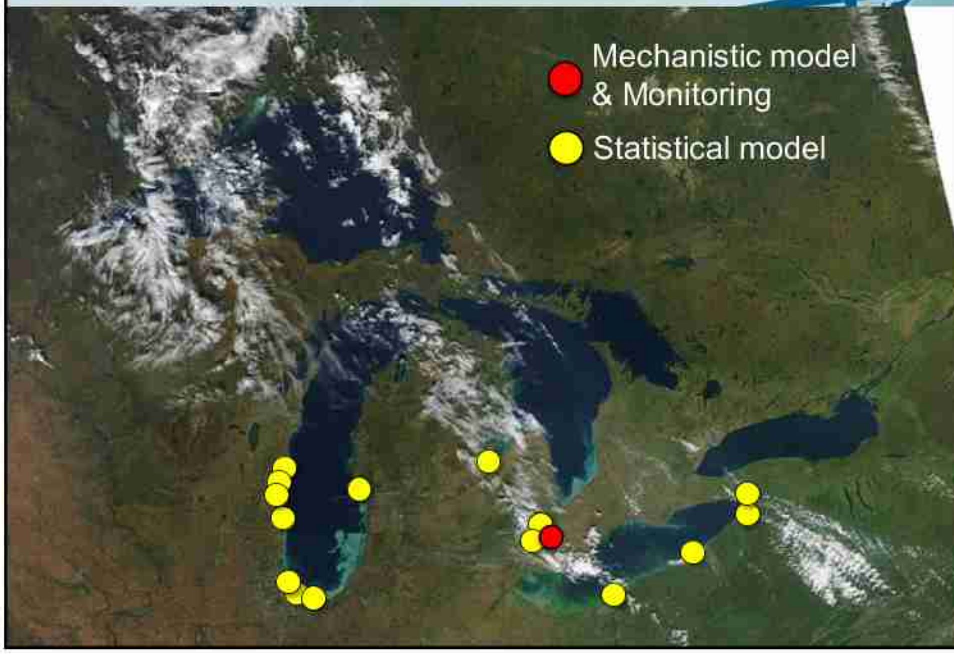
Next Steps

- The role of internal loading on cyanobacteria recruitment and community composition.
- Image Flow Cytometry applications to examine phosphatase activity and cyanotoxin production.
- Saginaw Bay and Lake Erie?


NOAA Center of Excellence for Great Lakes and Human Health
Monitoring and Modeling of E. coli for Beach Water Quality
Eric J. Anderson, Ph.D.
NOAA Great Lakes Environmental Research Laboratory
Director, Center of Excellence for Great Lakes and Human Health
NOAA
CILER
Sea Grant
Michigan


Modeling
Models
Pathogen Forecast
Statistical Model
- Virtual Beach
Statistical Beach Pathogen Forecast
Meteorology
- Observations
- NWS models
Hydrodynamic Model
- Currents, waves
Bacteria Particle Model
Mechanistic Beach Pathogen Forecast
Watershed Model
- runoff, bacteria load
Linked mechanistic model
Validation
Monitoring
Beach Sampling
- Coastline
- Transects
- Time-series
- Storm
Processing
- IDEXX
- Membrane Filtration
Bacteria Concentration
- Bayesian interval
- CFU
- MPN

CEGLHH Model Sites



Monitoring: Metro Beach (Detroit)

- IDEXX Colilert (Quanti-tray 2000)
  - 1x dilution on all samples
  - 10x dilution on event and watershed samples
- Membrane Filtration using modified mTEC agar
  - 1x, 10x, and 100x dilutions on all samples
  - 1000x dilutions on event and watershed samples

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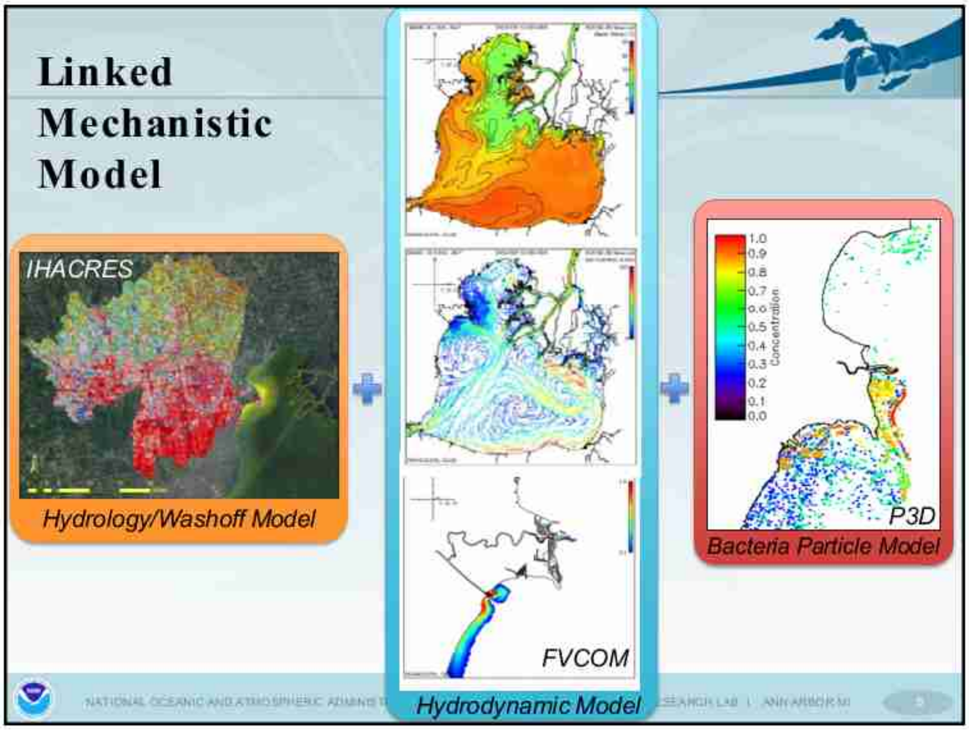
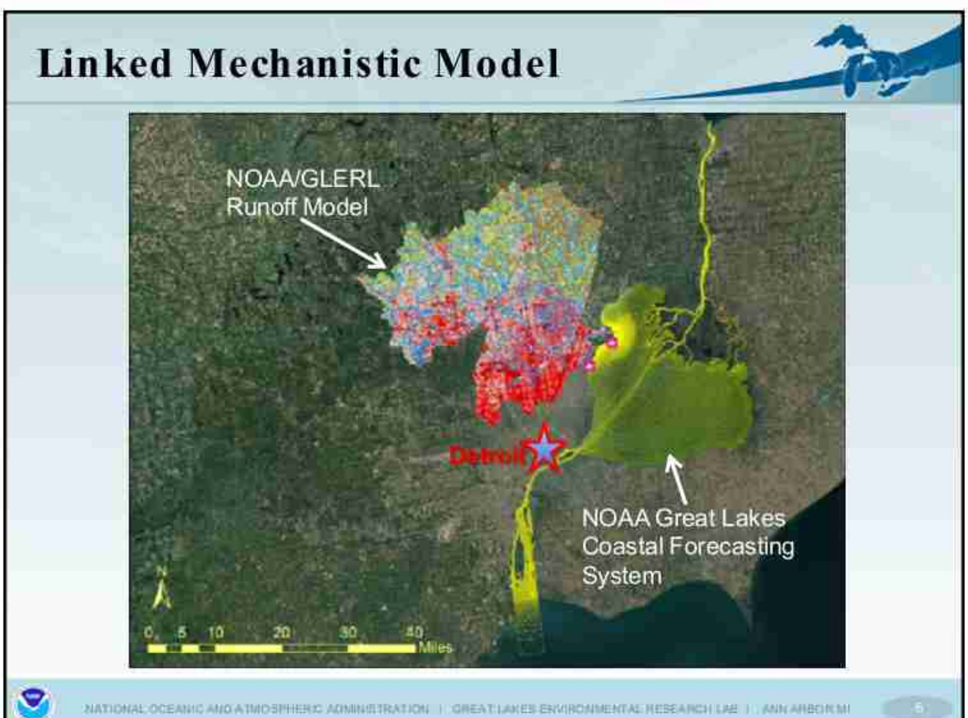
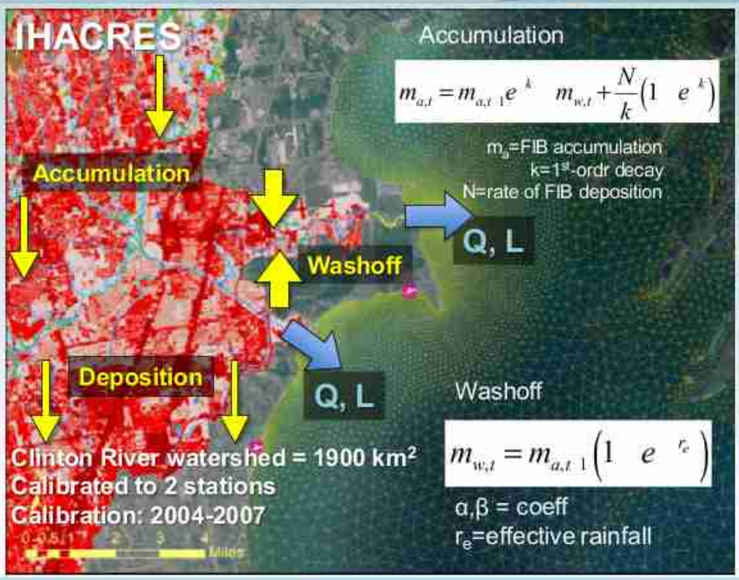

Linked Mechanistic Model
IHACRES
Hydrology/Washoff Model
FVCOM
Hydrodynamic Model
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Concentration
P3D
Bacteria Particle Model


Linked Mechanistic Model
NOAA/GLERL
Runoff Model
Detroit
NOAA Great Lakes
Coastal Forecasting
System
N
0 5 10 20 30 40
Miles
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION | GREAT LAKES ENVIRONMENTAL RESEARCH LAB | ANN ARBOR MI

Hydrologic-Hydrodynamic-Bacteria



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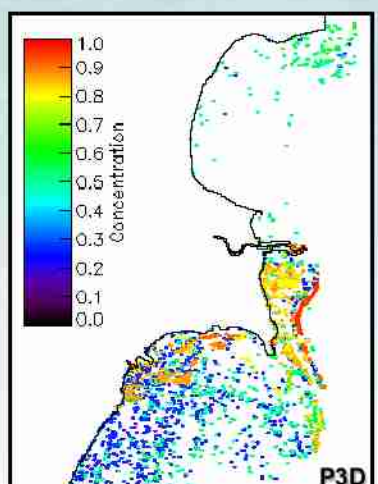
Hydrologic-Hydrodynamic-Bacteria



Lagrangian Particle Model (P3D)
- 3d particle trajectory *Bennett and Clites, 1987*
  - Smagorinsky horiz. diffusion
  - Random walk vertical diff.
- organisms => particles
- 1st order decay

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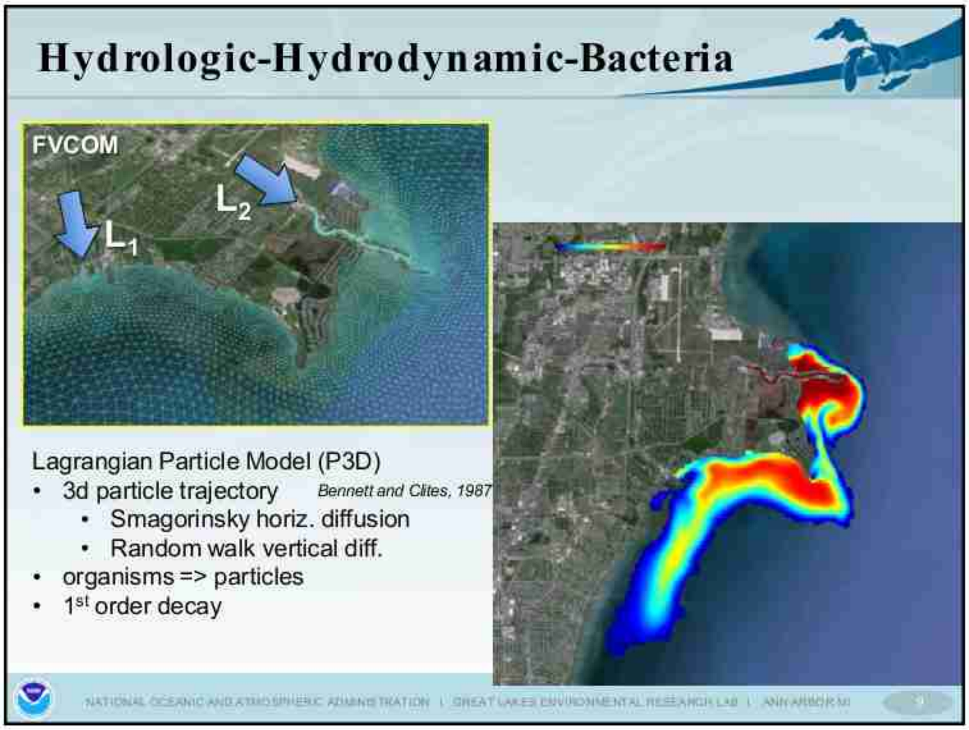

Hydrologic-Hydrodynamic-Bacteria
FVCOM
L1
L2
Lagrangian Particle Model (P3D)
• 3d particle trajectory
Bennett and Clites, 1987
• Smagorinsky horiz. diffusion
• Random walk vertical diff.
• organisms => particles
• 1st order decay
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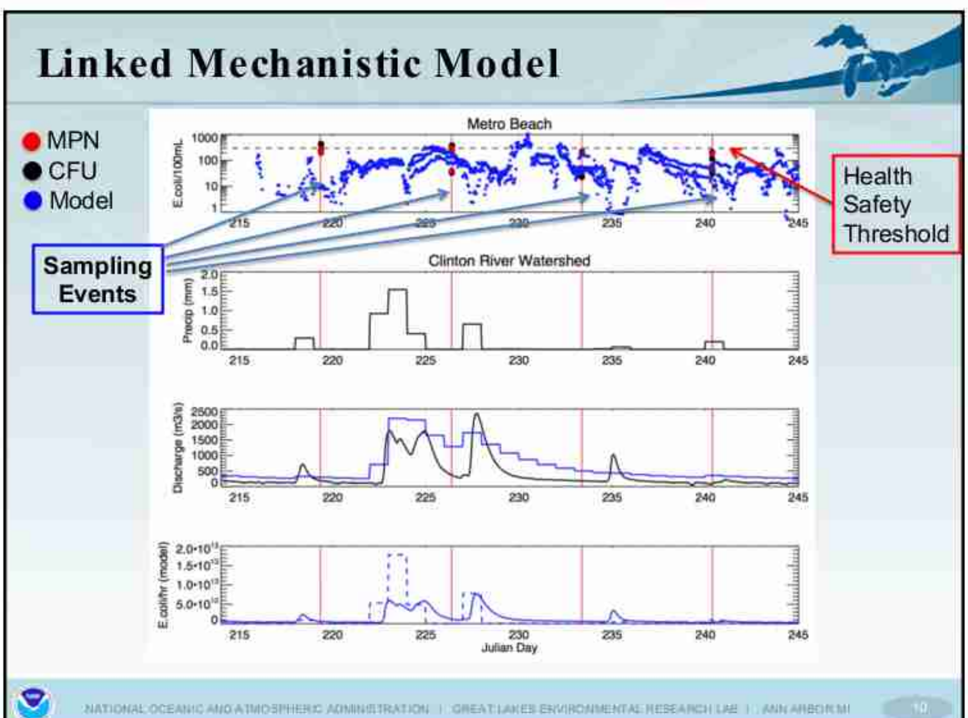


Linked Mechanistic Model
MPN
CFU
Model
Sampling Events
Health Safety Threshold
Metro Beach
E.coli/100mL
Clinton River Watershed
Precip (mm)
Discharge (m3/s)
E.coli/hr (model)
Julian Day
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION | GREAT LAKES ENVIRONMENTAL RESEARCH LAB | ANN ARBOR MI

Muskegon Lake Macrophytes

Muskegon Lake Area of Concern Habitat Restoration Project Partners

Muskegon Lake Habitat Restoration Project

- $10 million project
  - NOAA – American Recovery and Reinvestment Act
- Addresses several BUIs
- Restoration goals:
  - "Soften" hardened shoreline areas (3,050 m)
  - Create or restore wetlands (11 ha)
  - Remove unnatural fill (10 ha)
- Restoration design, construction, and monitoring

Monitoring

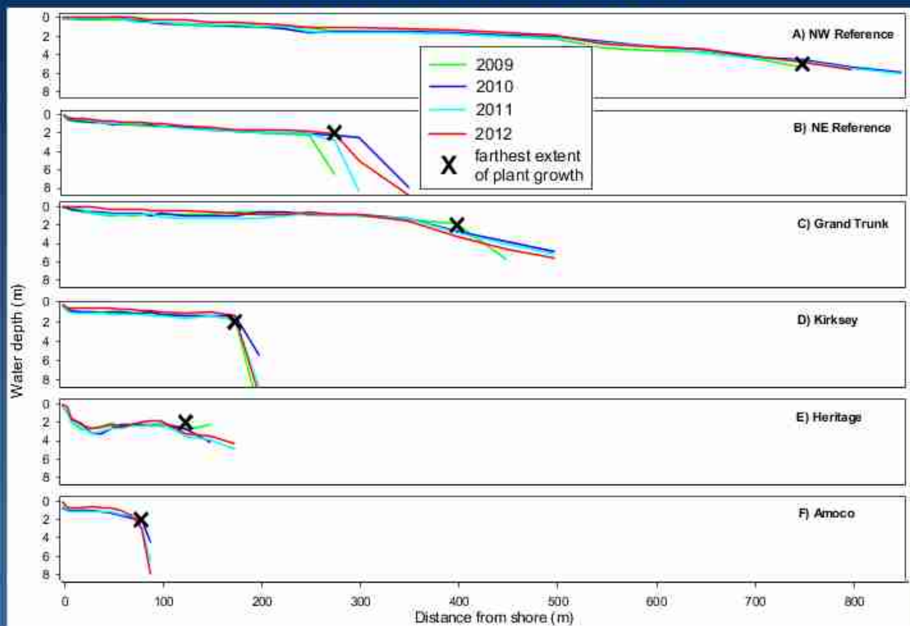
- 3 monitoring elements
  - Macrophytes
  - Fish
  - Socio-economics
- Pre-restoration monitoring in 2009 and 2010
- Post-restoration monitoring in 2011and 2012

Macrophyte Assessment Methods

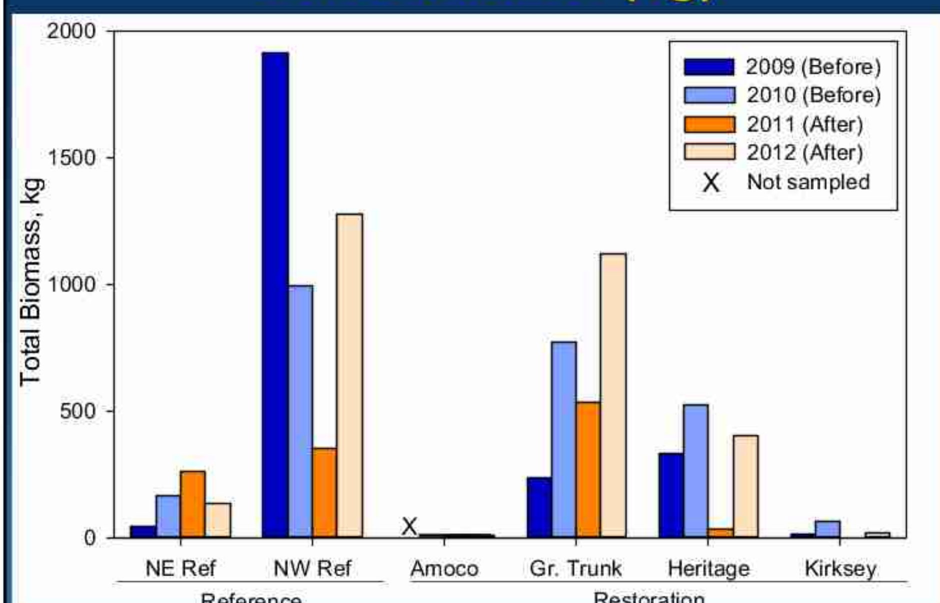
- 6 study sites: 2 reference, 4 restoration
- Sample at ~peak biomass (mid-August)
- Transects perpendicular to shore
  - 0-5 m: every 1 m
  - 10-100 m: every 10 m
  - 100-300 m: every 25 m
  - 300+ m: every 50 m

Macrophyte Assessment Methods

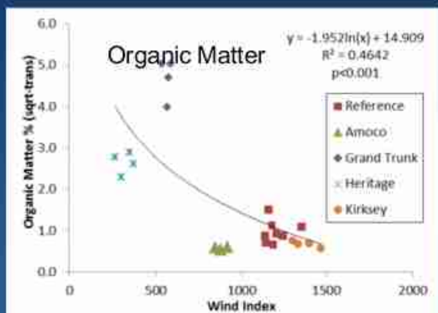
Transect Profiles

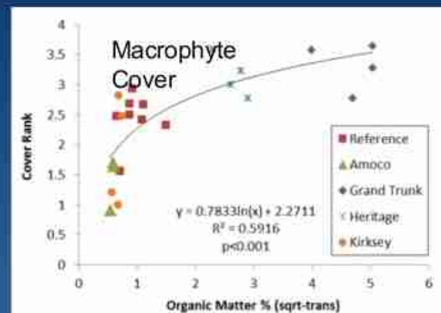


Total Biomass (kg)



Regression Analysis





Wind/Wave Exposure → Sediment Organic Matter → Macrophyte Cover

Conclusions

- Short-term negative impact of restoration
- Strong site effect may dilute restoration signal
- Longer-term monitoring needed
  - Macrophyte recovery/response time
  - Understanding environmental vs. restoration effects
  - Water level and climatic variability

Next Steps

Information Gaps:

- Macrophyte analysis should be updated with completion of restoration
- Better link macrophyte to other structural and functional attributes

Collaboration with NOAA:

- Invasive species inventory?
- Food web modeling?

Evolutionary responses of aquatic invasive species to management

Ryan A. Thum
Robert B. Annis Water Resources Institute
Grand Valley State University

Invasive Species & Management

How to balance prevention effort?

Finding needle in a haystack?

prevention

To manage or not to manage?

Risk of low abundance → high abundance?

Risk of poor control?

Risk of collateral damage?

eradication

control; restoration

Native range → Introduction → Establishment → Spread → Impact

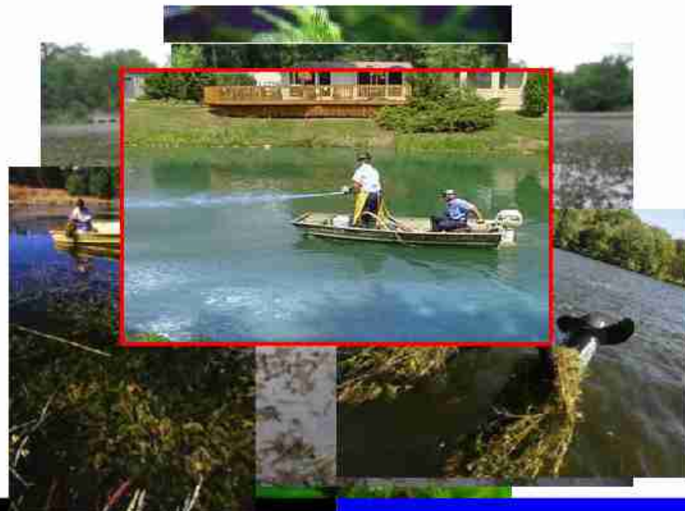
Ecological processes

Rapid evolution?

Partnerships
Eurasian watermilfoil management

Background

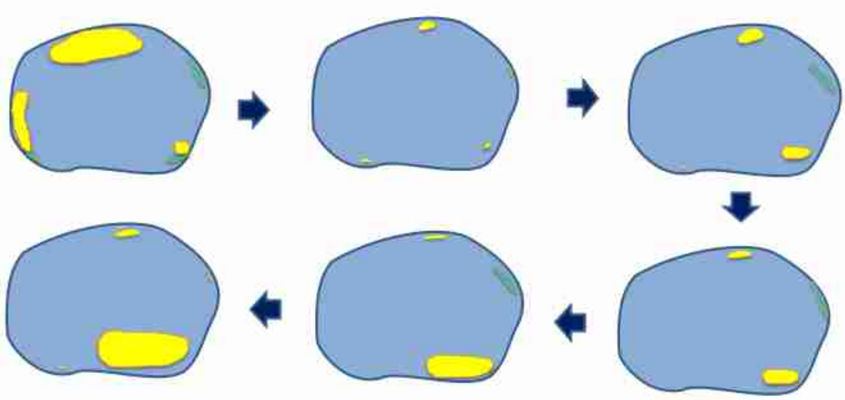
Eurasian watermilfoil



Partnerships
Eurasian watermilfoil management

Background
Management outcome scenarios

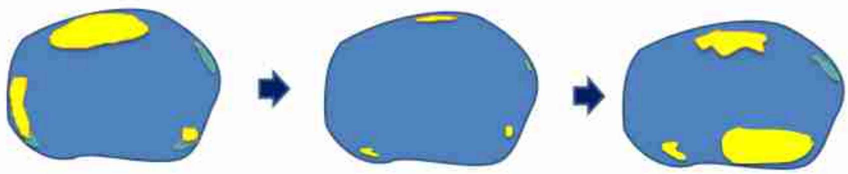
Scenario 1: Acceptable relief



Partnerships
Eurasian watermilfoil management

Background
Management outcome scenarios

Scenario 2: Fast growth (limited relief)



Partnerships
Eurasian watermilfoil management

Background
Management outcome scenarios

Scenario 3: Poor control (no relief)

Partnerships
Eurasian watermilfoil management

Background
Management outcome scenarios

Explanations for management outcomes

Traditional

Herbicide choice and application

Random environmental

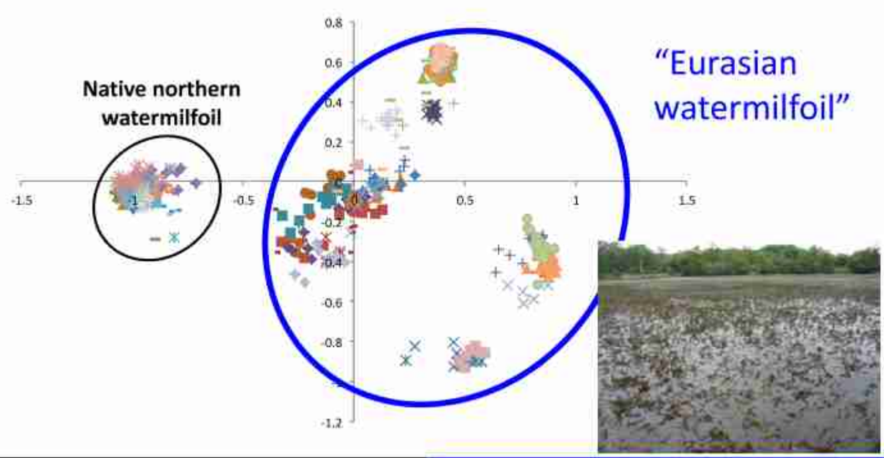
Physical/chemical factors

Cryptic diversity and evolutionary change

Partnerships
Eurasian watermilfoil management

Background
Management outcome scenarios
Cryptic diversity

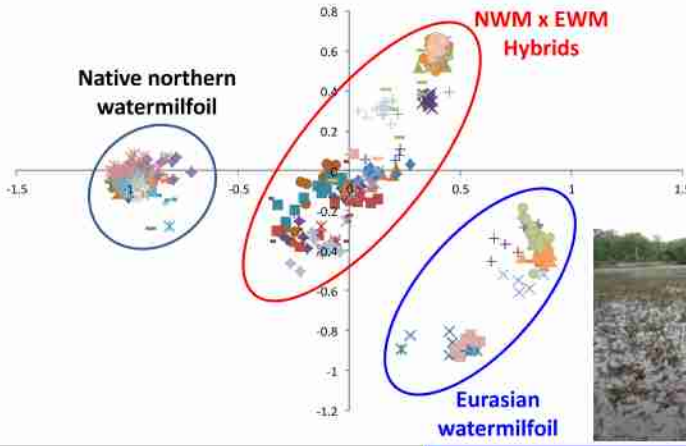
Cryptic diversity



Partnerships
Eurasian watermilfoil management

Background
Management outcome scenarios
Cryptic diversity

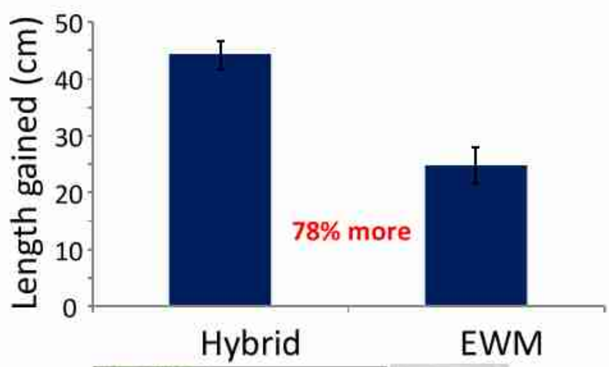
Cryptic diversity



Partnerships
Eurasian watermilfoil management

Background
Management outcome scenarios
Cryptic diversity

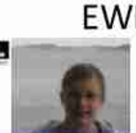
Hybrid Eurasian watermilfoils are weedier




Evolutionary Applications

ORIGINAL ARTICLE

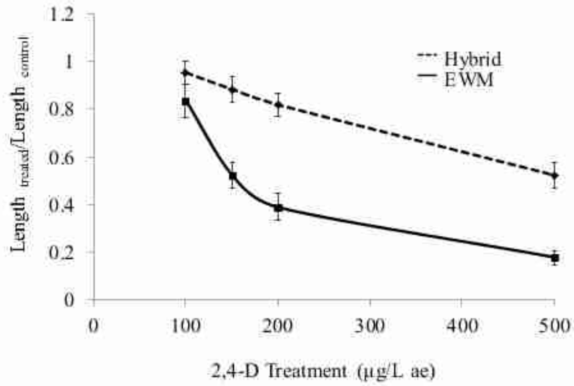
Hybrid watermilfoil lineages are more invasive and less sensitive to a commonly used herbicide than their exotic parent (Eurasian watermilfoil)



Partnerships
Eurasian watermilfoil management

Background
Management outcome scenarios
Cryptic diversity

Hybrids can be less sensitive to 2,4-D herbicide

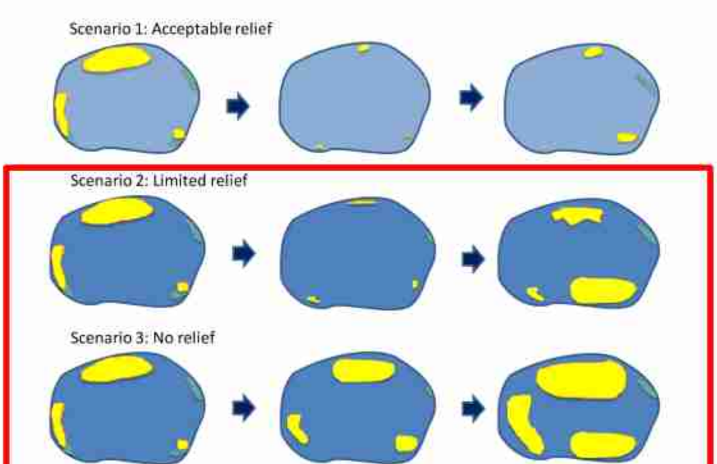


Hybrid EWM

Partnerships
Eurasian watermilfoil management

Background
Management outcome scenarios
Cryptic diversity

Management scenarios



Numerical simulation of contemporary evolution in managed lakes

Or, "How much evolution will get a manager fired?"

Empirical data

Simulations; sensitivity

Poor management

- Herbicide rate (μ, σ^2)
- Efficacy (% reached)

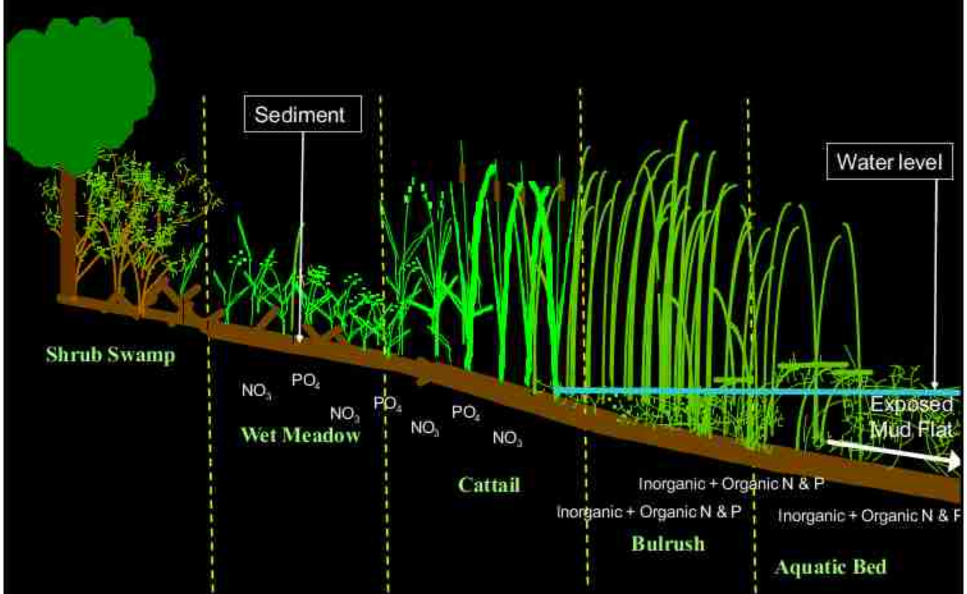
Evolution

- Sexual/asexual recruit.
- Veg. growth
- Herb. resistance

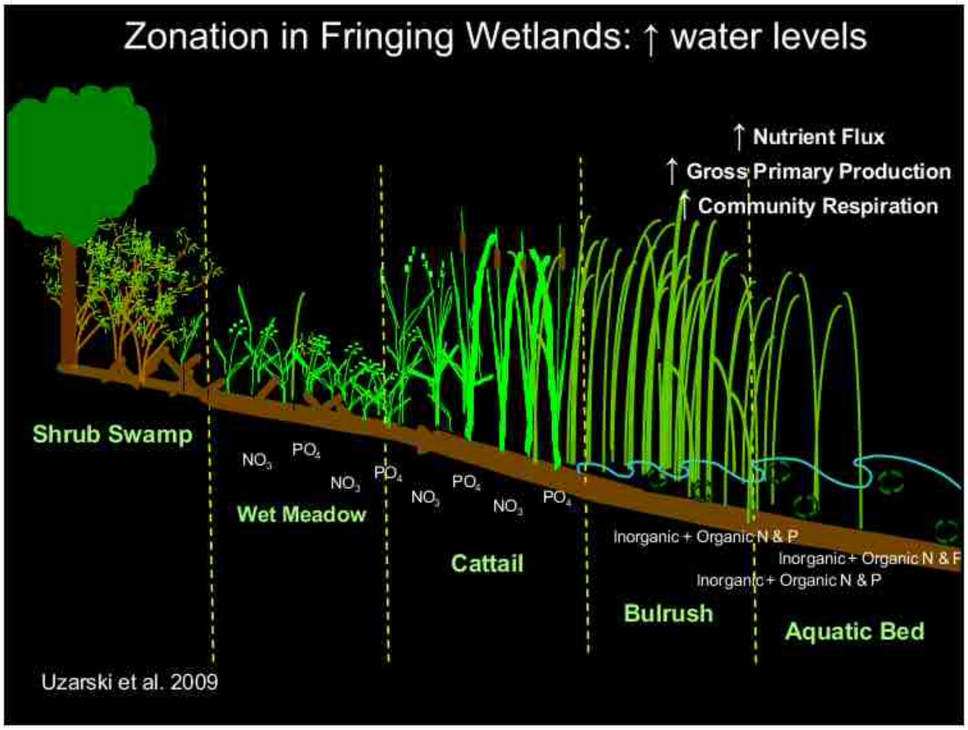
Hydrology of Coastal Wetlands: Muskegon Lake

- Vegetation key driver
- Over 260 invertebrate species
- Over 80 fish species, of which 50 are wetland-dependent
- Greatest diversity and density generally found at intermediate positions along lake-to-shore gradient

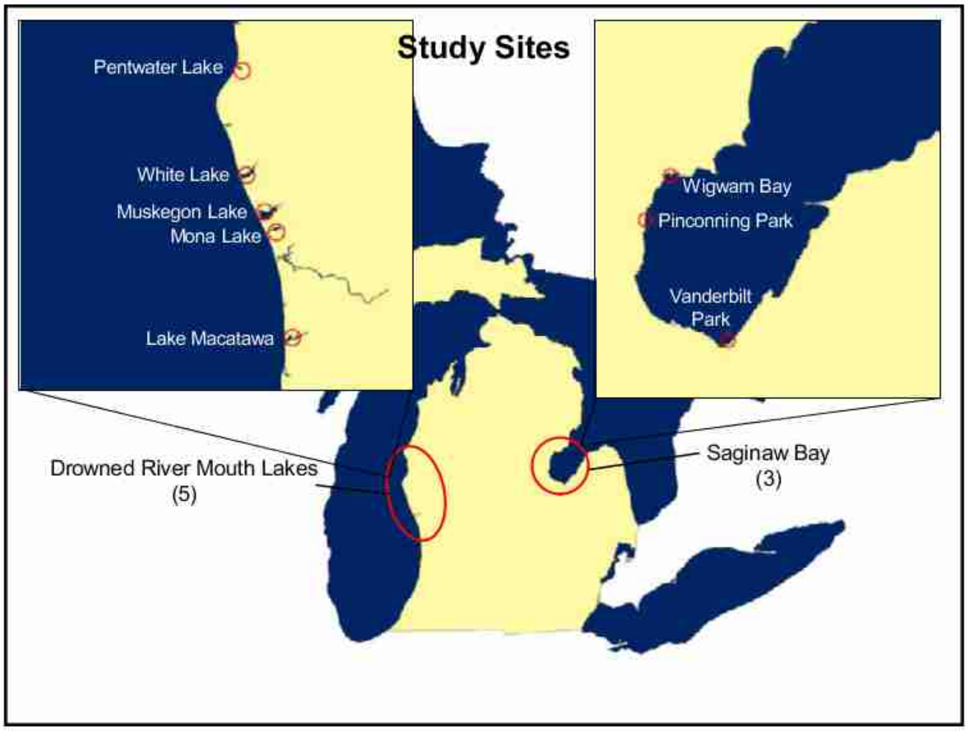
Zonation in Fringing Wetlands: ↓ water levels



Modified from Uzarski et al. 2009

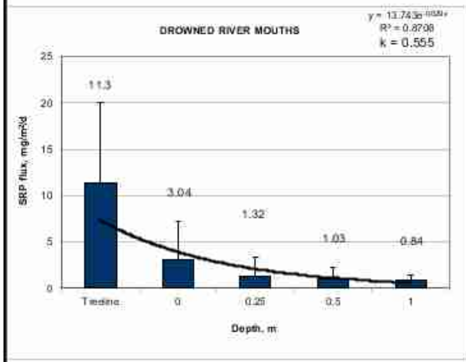


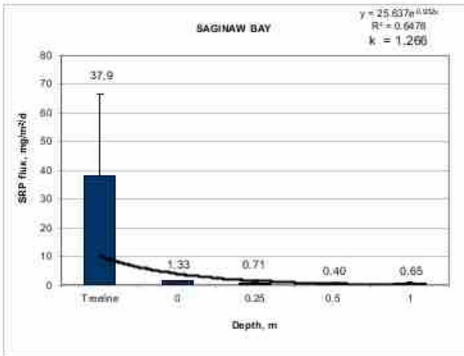
Zonation in Fringing Wetlands: ↑ water levels
↑ Nutrient Flux
↑ Gross Primary Production
↑ Community Respiration
Shrub Swamp
NO3
PO4
NO3
PO4
Wet Meadow
NO3
PO4
NO3
PO4
Cattail
Inorganic + Organic N & P
Inorganic + Organic N & F
Inorganic + Organic N & P
Bulrush
Aquatic Bed
Uzarski et al. 2009



Study Sites
Pentwater Lake
White Lake
Muskegon Lake
Mona Lake
Lake Macatawa
Wigwam Bay
Pinconning Park
Vanderbilt Park
Drowned River Mouth Lakes (5)
Saginaw Bay (3)

Ortho-phosphate (mg/m^2/d)





- Exponential decline with depth

Muskegon Lake Water Level Scenarios: PO_4

<u>Decline:</u>

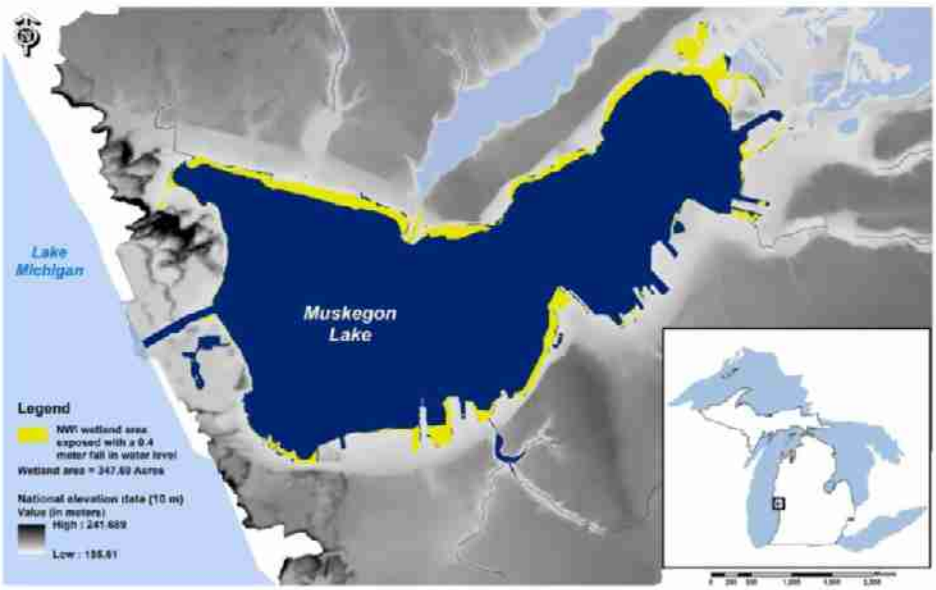
- 0.4 m; then inundation
- 0.8 m; then inundation
- 1.5 m; then inundation

<u>Increase:</u>

- 0.4 m

Base Water Level

-0.4 m decline: 141 ha*

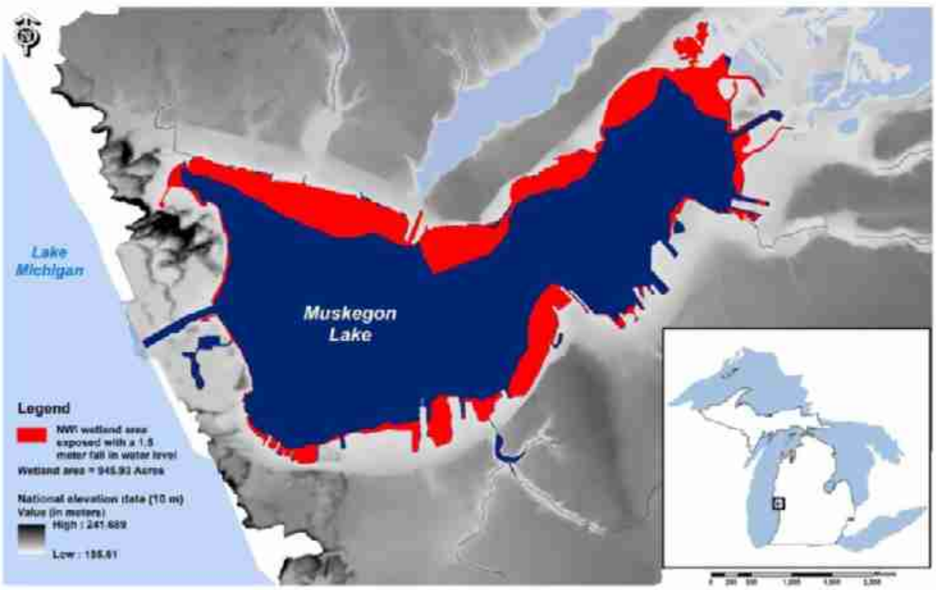


*includes only wetlands (NWI)

-0.8 m decline: 229 ha*

*includes only wetlands (NWI)

-1.5 m decline: 383 ha*



*includes only wetlands (NWI)

+0.4 m increase: 25 ha*

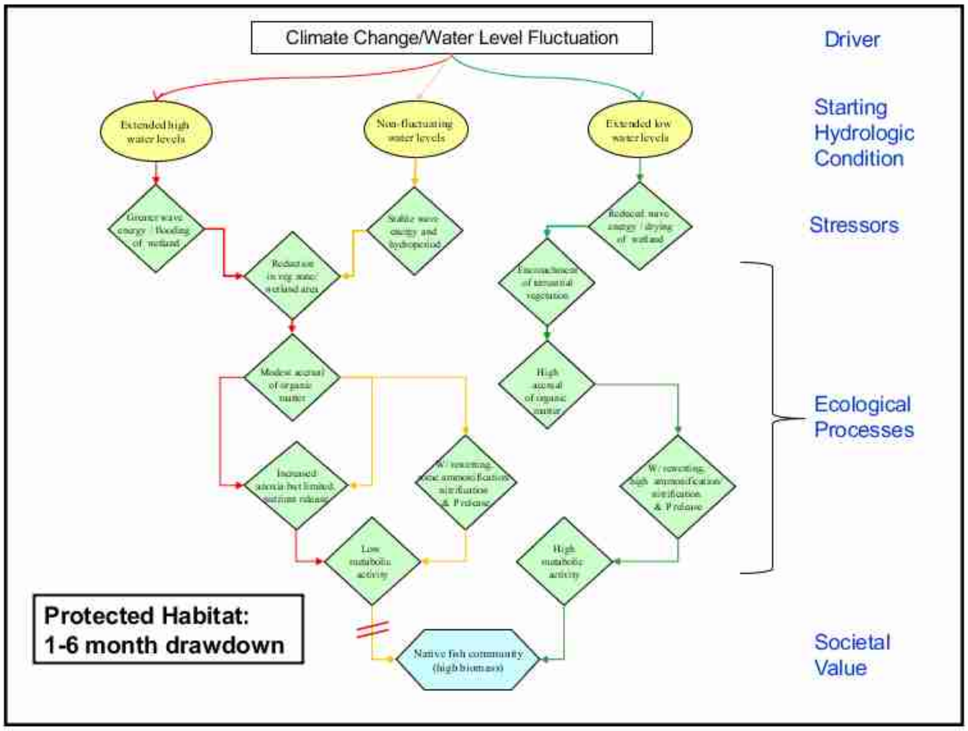
*includes only wetlands (NWI)

Phosphate: Muskegon Lake

Water Level Change (m)	Area Exposed / Flooded (ha)
- 0.4	140.7
-0.8	229.1
-1.5	382.8
+0.4	25.4

Conclusions

- Water level fluctuations can impact sediment-water nutrient release
- Nutrient flux may have localized ecological implications
- Work is amenable to conceptual and hydrodynamic modeling



Next Steps

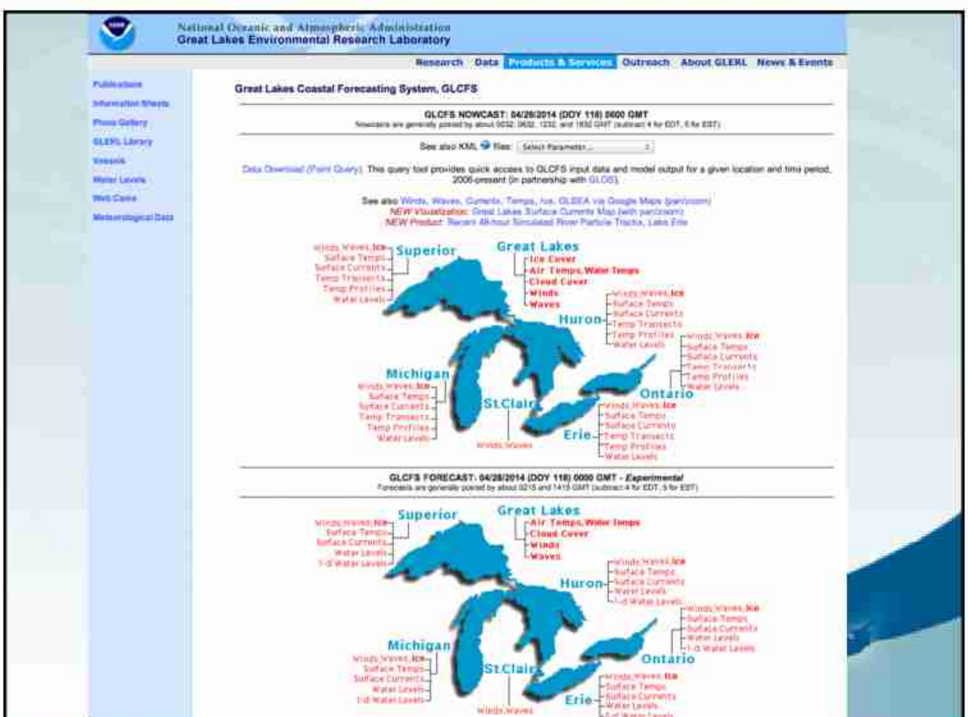
Information Gaps:

- Biotic response to nutrient pulses
- Impact of restoration on flux
- Field validation of lab results
- Key species for coastal food webs

Collaboration with NOAA:

- Food web modeling
- Hydrodynamic modeling

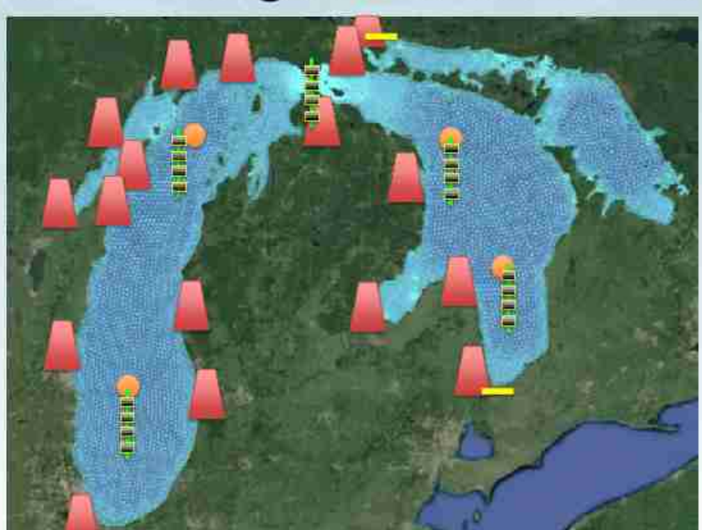

Great Lakes Coastal Forecasting System (GLCFS):
The Next Generation
Eric J. Anderson, Ph.D.
NOAA Great Lakes Environmental Research Laboratory


National Oceanic and Atmospheric Administration
Great Lakes Environmental Research Laboratory
Research
Data
Products & Services
Outreach
About GLERL
News & Events
Great Lakes Coastal Forecasting System, GLCFS
GLCFS NOWCAST
GLCFS FORECAST
Superior
Great Lakes
Huron
Michigan
St.Clair
Erie
Ontario
Ice Cover
Air Temps, Water Temps
Cloud Cover
Winds
Waves

Research-to-Operations

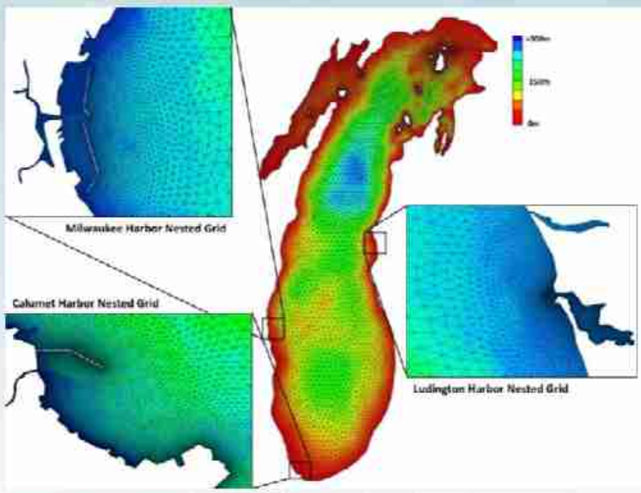
- **5-year plan between OAR and NOS**
  - Develop FVCOM for each lake
  - Hindcast skill assessement
    - surface temps, currents, water levels
  - Nowcast/Forecast skill assessment (5-day forecast)
  - Lake Erie (FY14)
  - Lake Michigan-Huron (FY15)
    - Combined lake model w/ Straits of Mackinac
  - Lake Superior (FY16)
  - Lake Ontario (FY17)
- *Huron-Erie Corridor (HECWFS)*
  - *St. Clair River, Lake St. Clair, Detroit River*
- *Upper St. Lawrence River (USL)*

Lake Michigan-Huron FVCOM



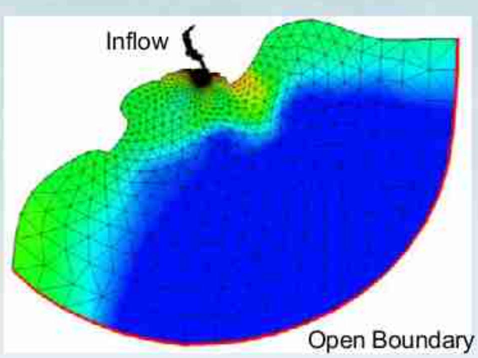
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION | GREAT LAKES ENVIRONMENTAL RESEARCH LAB | ANN ARBOR MI

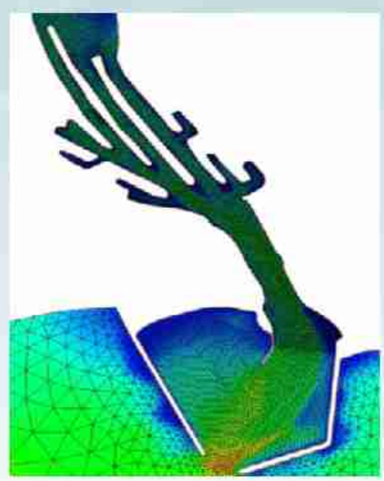
Nested Nearshore Modeling



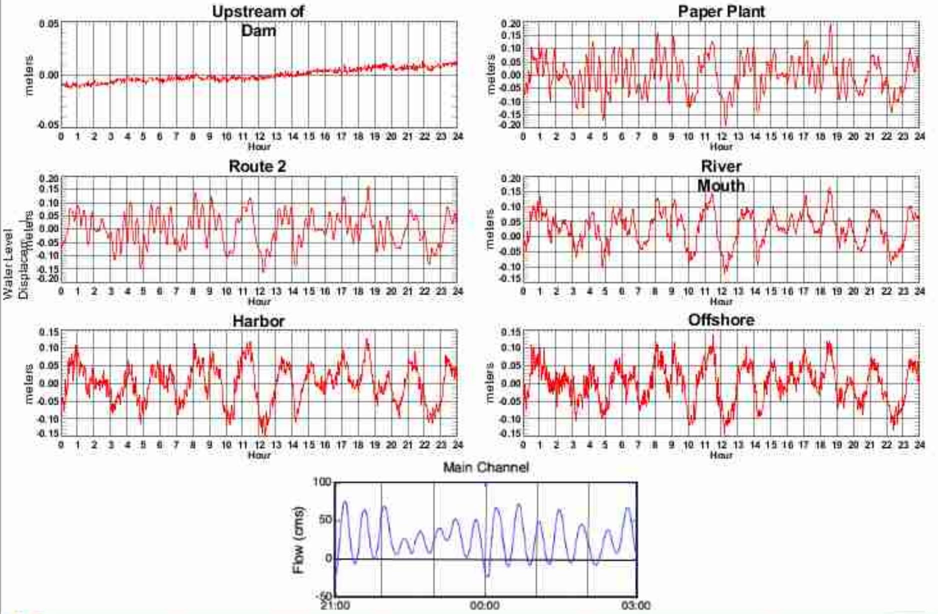
- Tier I – GLCFS Lake Michigan hydrodynamic model
- Tier II – nested Muskegon model?

Manistique Model



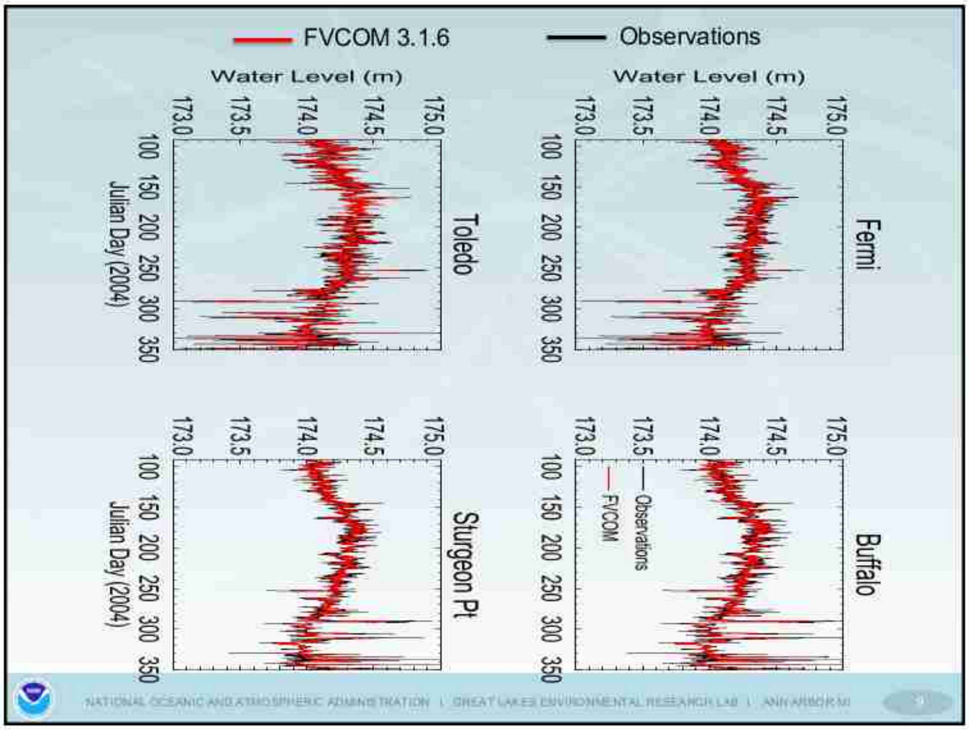


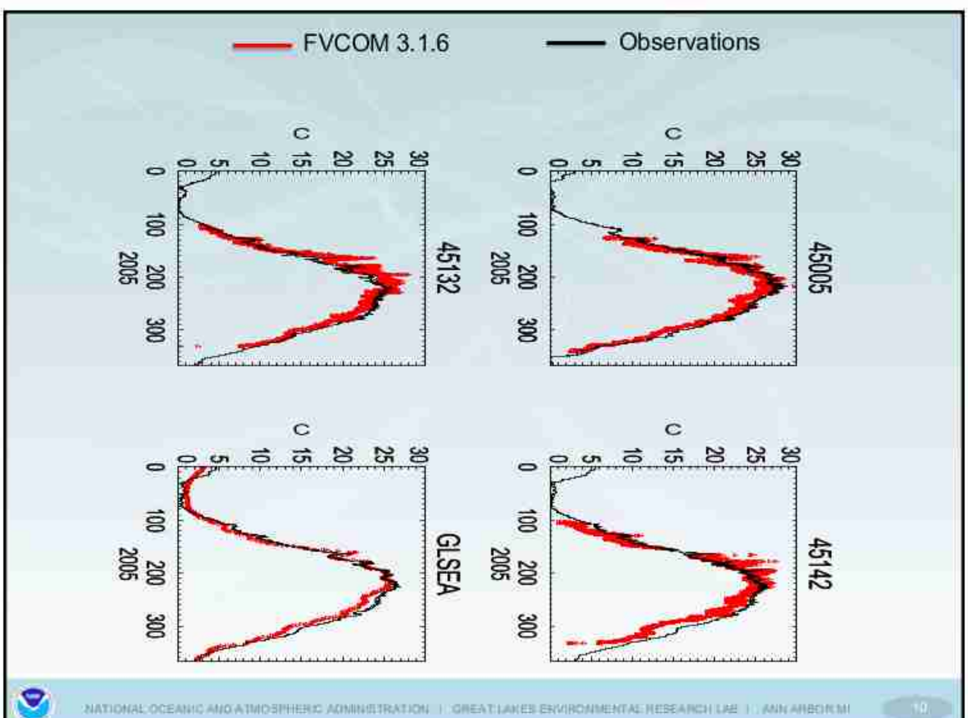
Observations - Seiche

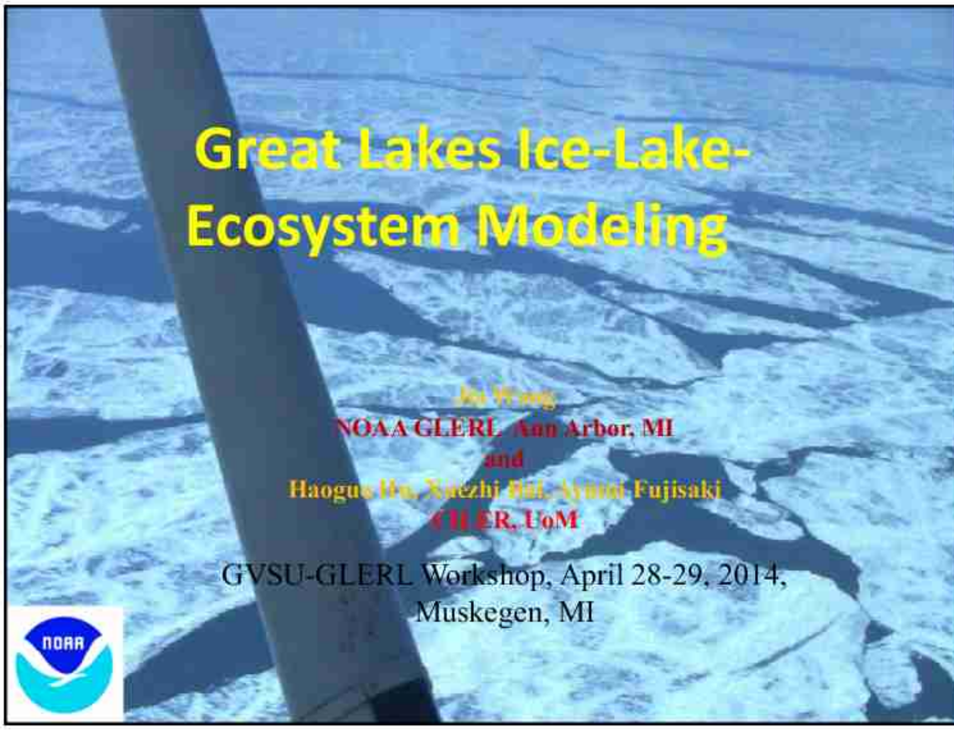


Lake Erie FVCOM

- Open boundaries at Detroit River (inlet) and Niagara River (outlet)
- Distributed surface forcing (wind, heat flux) via (i) stations, (ii) NDFD
- Validation: NOS water level gauges, NDBC buoys, 2004 ADCP measurements


FVCOM 3.1.6
Observations
Water Level (m)
Fermi
Buffalo
Toledo
Sturgeon Pt
Observations
FVCOM
Julian Day (2004)
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION | GREAT LAKES ENVIRONMENTAL RESEARCH LAB | ANN ARBOR MI

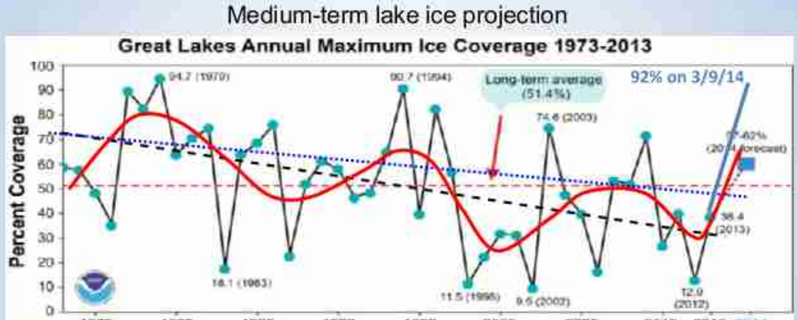

FVCOM 3.1.6
Observations
45005
45142
45132
GLSEA
C
2005
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION | GREAT LAKES ENVIRONMENTAL RESEARCH LAB | ANN ARBOR MI



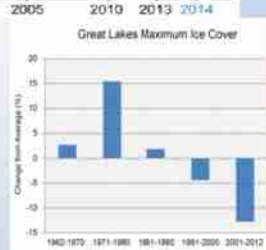
Current Research – <Jia Wang>

1. Great Lakes Ice: Research and Projection

Medium-term lake ice projection

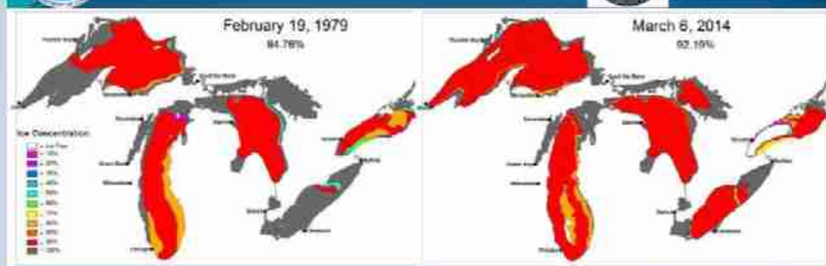


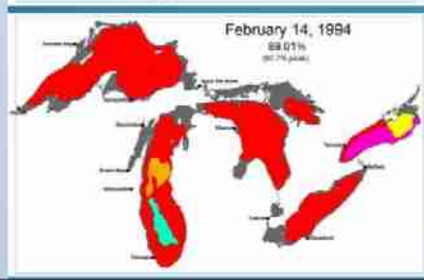
1. Linking PDO, AMO to Great Lakes ice
2. Add PDO, AMO, and cumulative freezing degrees days to the statistical regression model
3. Update Ice Atlas
4. Continue measuring ice thickness using helicopter



Great Lakes Ice Cover Maxima: 1979, 1994, 2014

Great Lakes Ice Cover Maxima GLERL

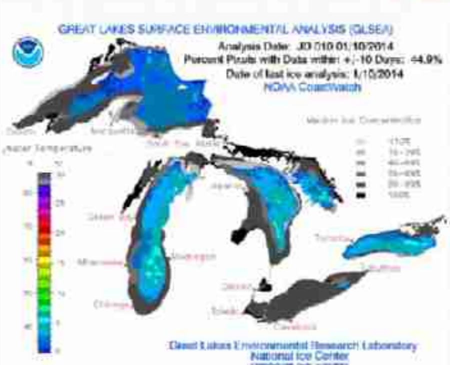




- **Historical maxima of Great Lakes ice**
  1. Feb 19, 1979: 94.76%
  2. March 6, 2014: 92.19%
  3. Feb. 1994: 90.7% - not pictured
- **Breakdown by lake** current (2014 peak; record)
  - Superior: 94.5% (95.74% - 3/5; 100% - 1996)
  - Michigan: 92.19% (92.98% - 3/5; 93.1% - 1977)
  - Huron: 96.30% (96.30% - 3/6; 98.3% - 1994)
  - St. Claire: 99.06% (99.18% - 2/2; no official rec.)
  - Erie: 96.40% (96.4% - 3/6; 100% - '78, '79, '96)
  - Ontario: 61.52% (61.52% - 3/6; 85.7% - 1979)

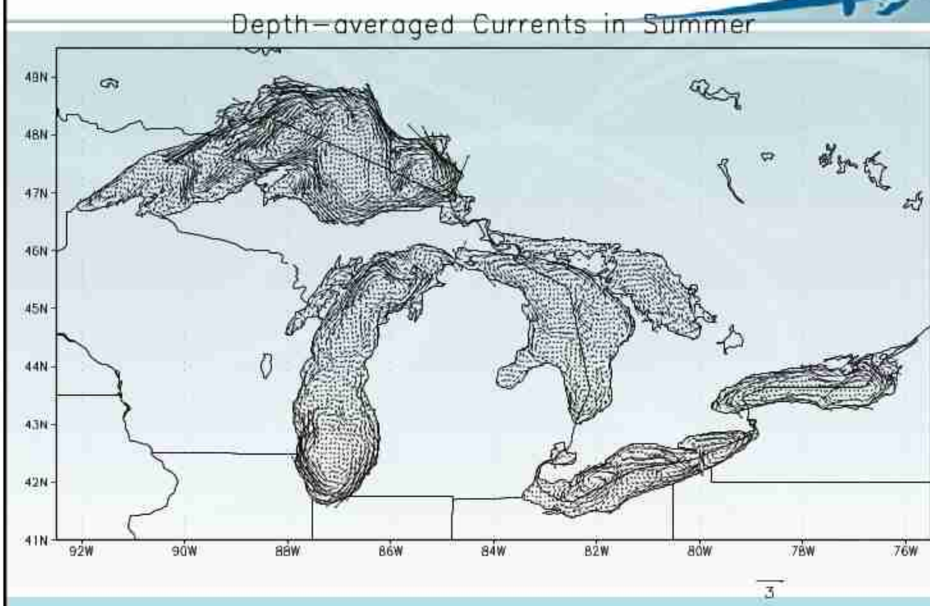
3

GLIM Prediction during 2013-14 ice season Using Great Lakes Ice-lake Model (GLIM)--POMice

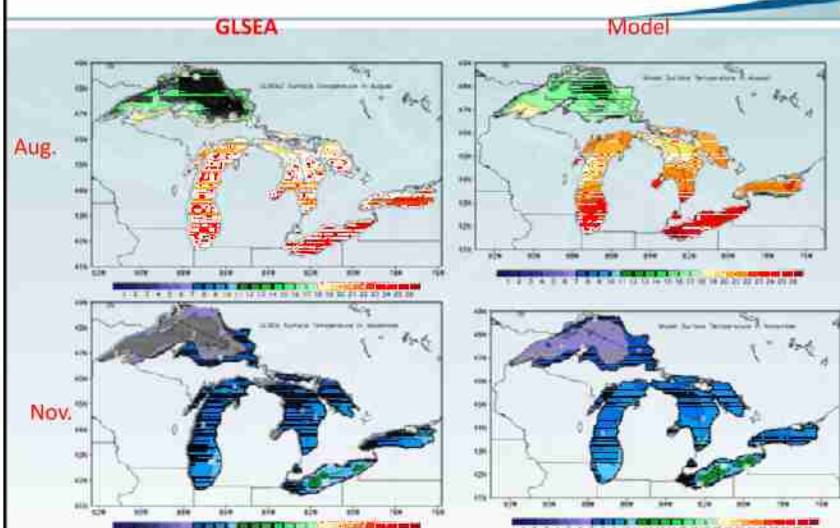


GLCFS:
http://www.glerl.noaa.gov/res/glcfs/

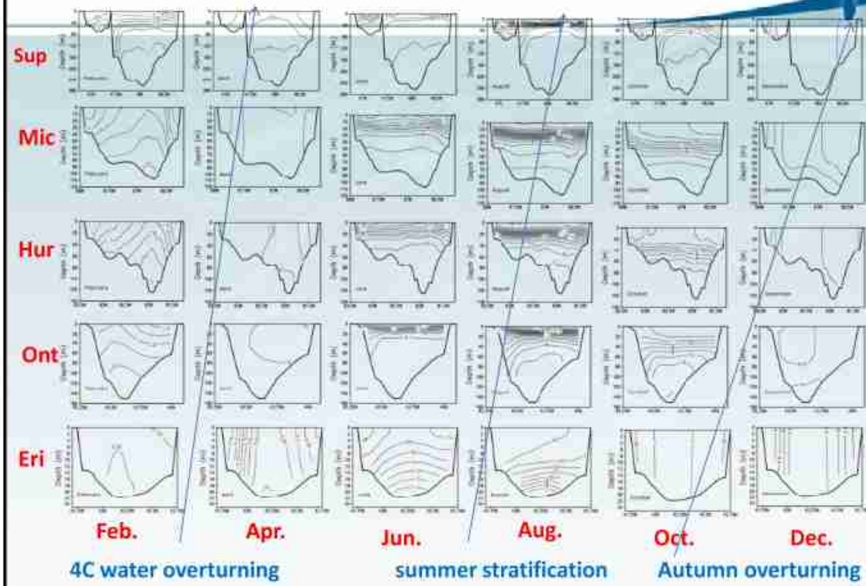
Model Results and Validation 1. Long term mean circulation



Model Results and Validation 2. Lake Surface Temperature



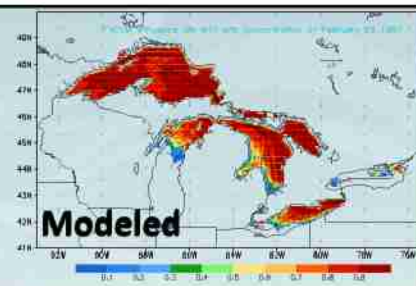
Model Results and Validation 3. Thermal Structure

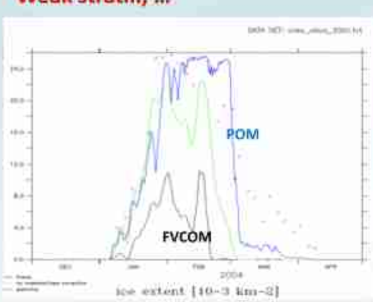


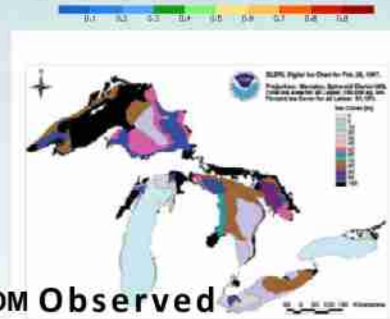
2. FVCOM

(Bai et al. 2013, OM; Fujisaki 2013, JGR)

Using FVCOM:
Unstable scheme=>
Larger viscosity=>
Increase mixing=>
Warmer T =>
Weak stratif., ...

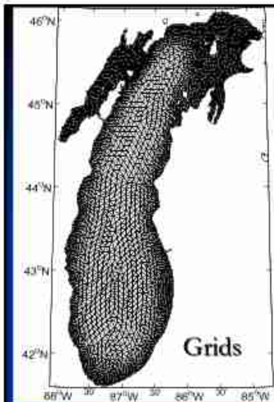


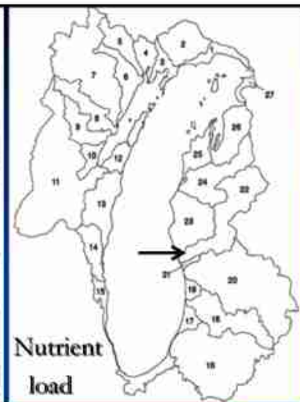


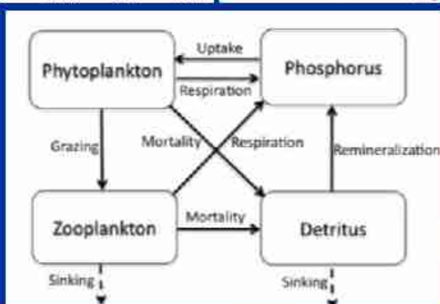


February 28 1997

1. Modify time integration scheme of FVCOM
2. Apply to GLCFS and hypothesis test
3. Linking coupled ice-ocean FVCOM/POM to regional climate model (Brent)
4. Climate scenario simulation for decision making





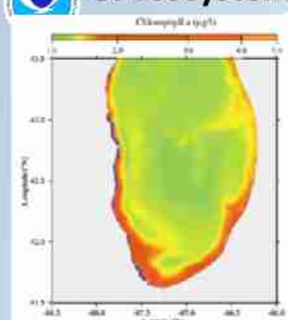


Great Lakes Coupled Physical-Ecological Model:

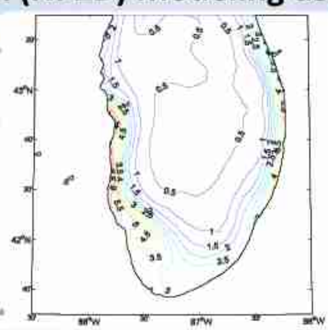
The physical fields derived from unstructured-grid ocean model (FVCOM 3.1) with turbulent closure scheme.

- Horizontal resolution: 9054 elements in 84.5° -88° W, 41.5° -46.1° N
- Vertical levels: 21 sigma layers
- Forcing: observed hourly wind and heat flux
- A wind-wave mixing parameter implemented to accurately simulate the mixed layer.
- 4-compartment NPZD model
- Inputs: 19 Rivers
- Rivers with runoff peak larger than $400 m^3/s$: Fox, St Joseph, Kalamazoo, Grand River (from USGS).

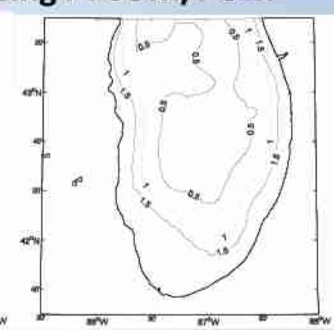
3. Ecosystem (NPZD) Modeling using FVCOM/POM



Chl in south Lake Michigan on March 25, 1998 (SeaWiFS)



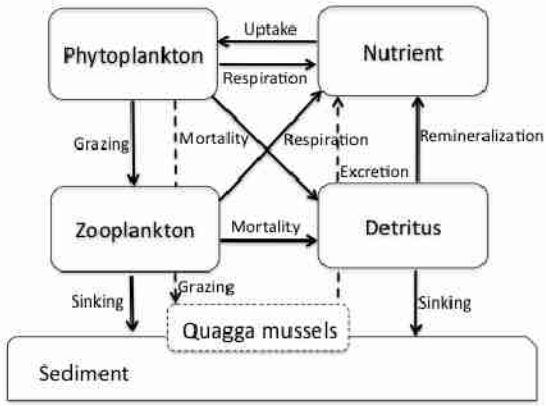
Simulated Chl with tributary loading



Simulated Chl without tributary loading

1. Using improved FVCOM (Luo et al. 2012; JGR), we will include quagga mussel (Hank and Mark), and *help* linking lower trophic level ecosystem (NPZD/water quality) to upper trophic level ecosystem (fish, Doran&Ed$Hongyan)
2. Work toward the Great Lakes Earth System Model (GLESM)

Proposed NPZD model with Quagga mussels in Lake Michigan using FVCOM



Under forcing of climate trend, extreme weather, storms, and river nutrient loads due to land use to investigate the interactions between the invasive stressor and climate stressor and the impacts on Great Lakes ecosystem

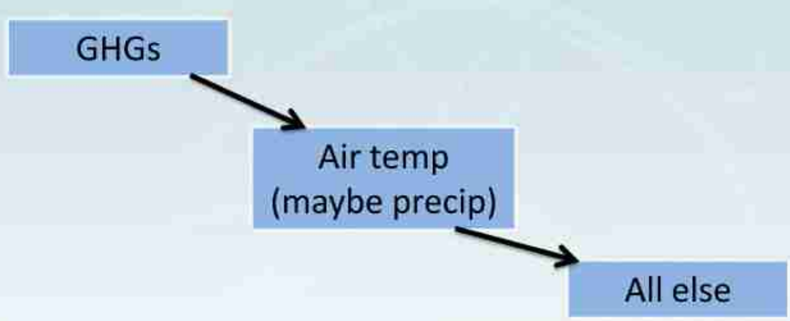
Great Lakes Regional Climate Modeling

Brent M. Lofgren
NOAA Great Lakes Environmental Research Laboratory
Ann Arbor, MI

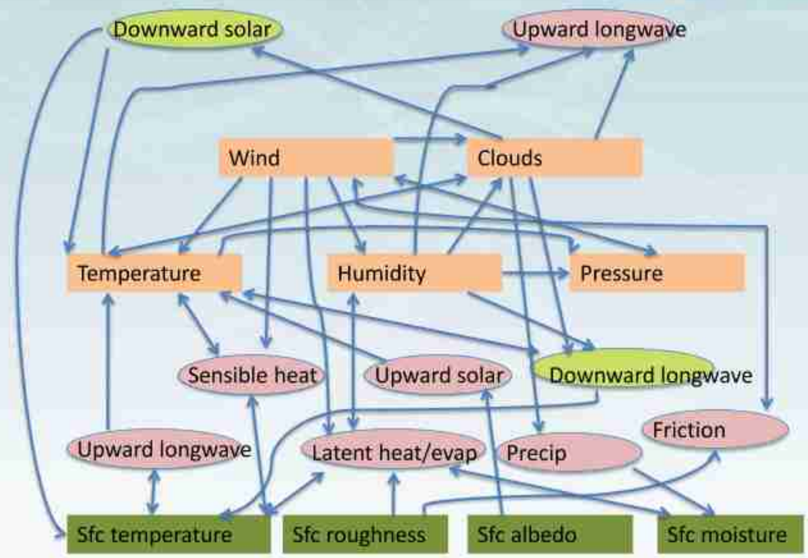
Presented at the GLERL-GVSU Lake Michigan-Muskegon Connectivity Workshop

April 29, 2014

Previously Assumed Chain of Causality



The Real World—Simplified



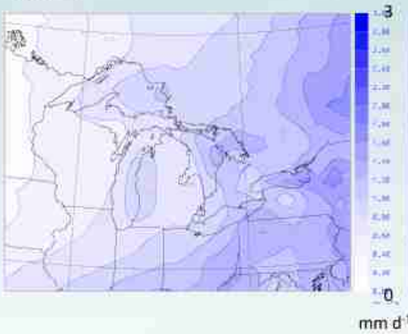
Regional climate modeling approach

Regional coupled modeling including GCM-based large-scale atmosphere and regional lake-land-air interactions

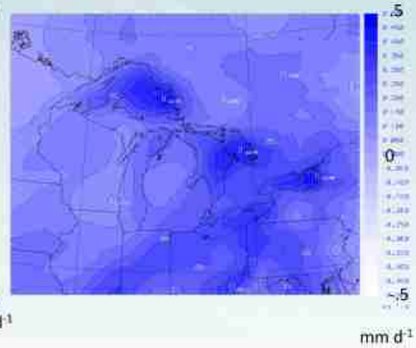
Other examples applied specifically to the Laurentian Great Lakes include MacKay and Seglenieks (2013), Bennington et al. (2014) , Gula and Peltier (2013), Music (2011)

Winter (DJF) precip rate

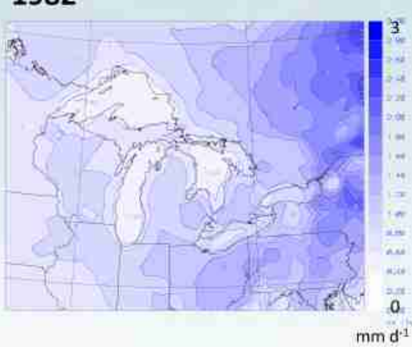
1982



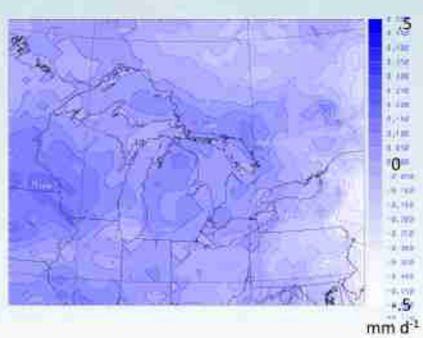
2056-1982



1982

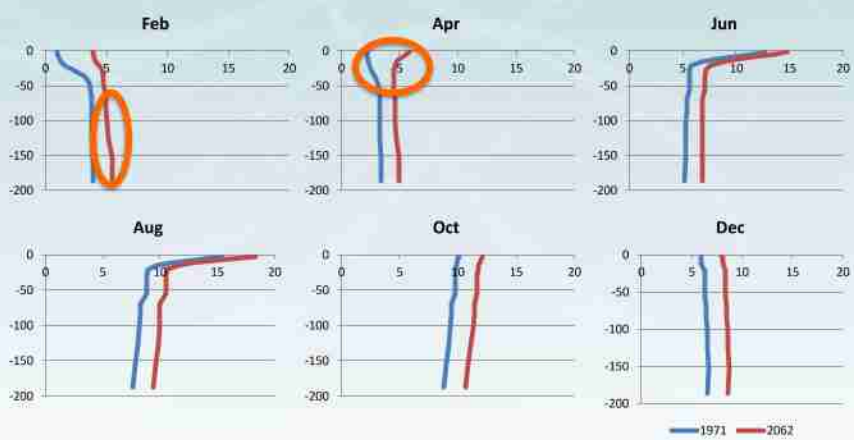


2056-1982

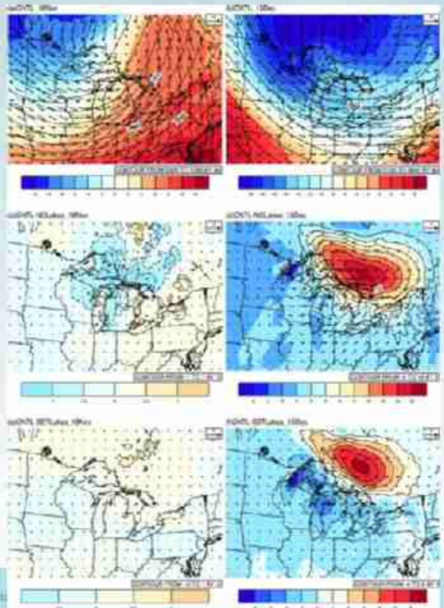


Precipitation minus evapotranspiration—2056 minus 1982

Water temperature (deg C) vs. depth (m)—central L. Michigan

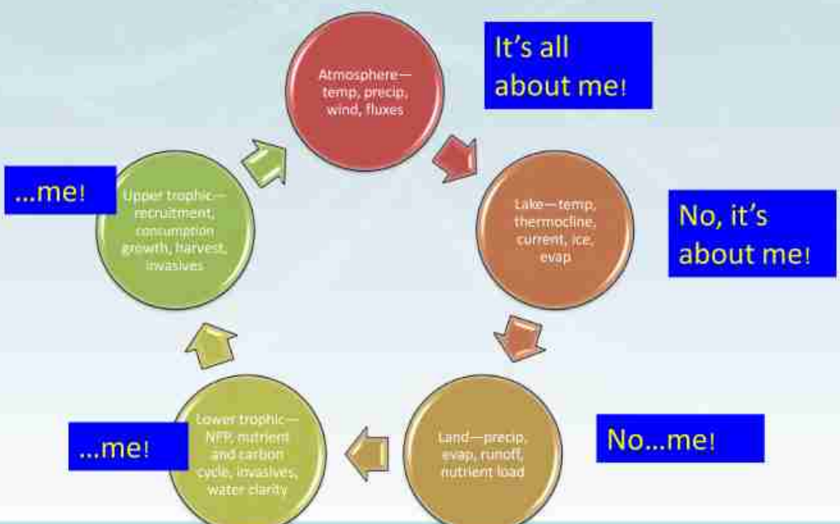


New Successor Model—WRF



Vector: U, V at 10 m
Shaded: T850
Contour: Z500

Future Directions – Earth System Model/Ecological Forecasting



Lake Michigan - Muskegon Lake Connectivity Workshop

Observing Systems and Instrumentation

Steve Ruberg

GLERL

April 29, 2014

GLERL Research Vessels

R/V Laurentian

Lake Michigan Offshore Monitoring

Monthly LTR Cruises

5501

Fast Response Buoy Tender

ReCON Buoys

Moored Instrumentation

5002 – "Storm"

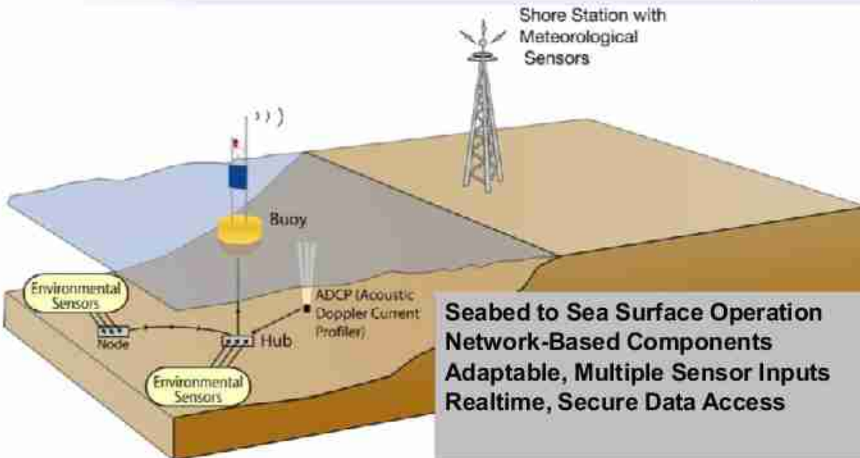
Remote Sensing Platform

Multi-beam & Sidescan Sonar

Remotely Operated Vehicles

Real-time Coastal Observation Network

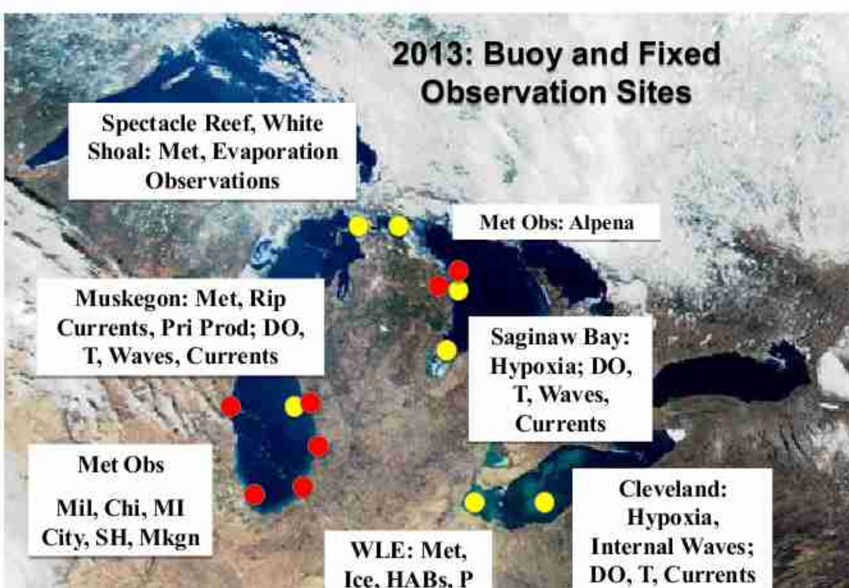
Successful ecosystem forecasting and forecast validation depend on the availability of data describing the present state of coastal waters at a variety of time and space scales.



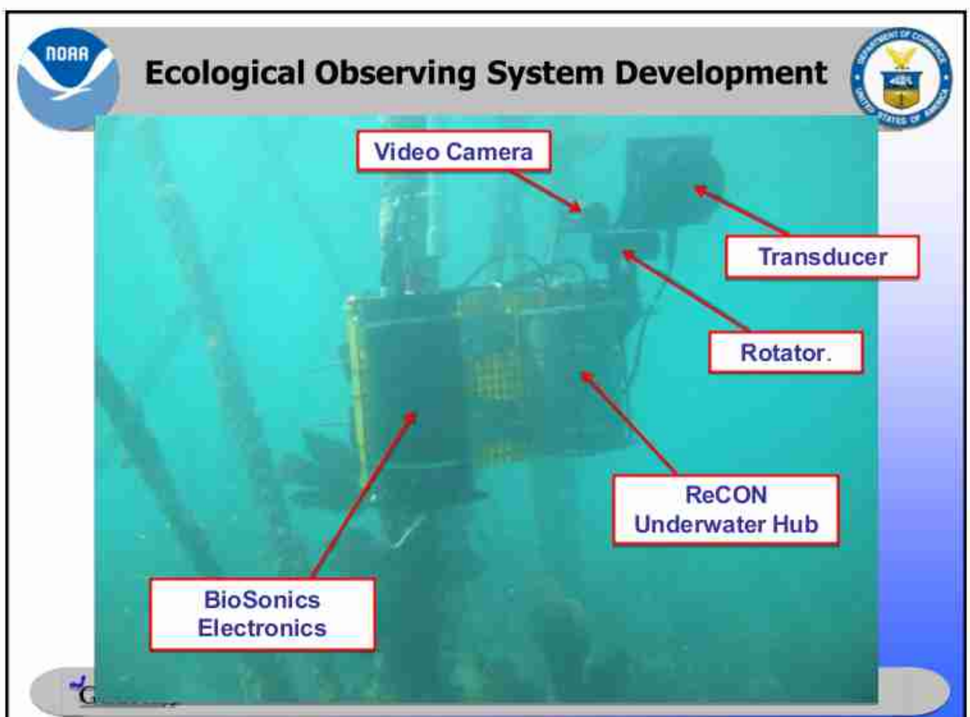
Seabed to Sea Surface Operation
Network-Based Components
Adaptable, Multiple Sensor Inputs
Realtime, Secure Data Access

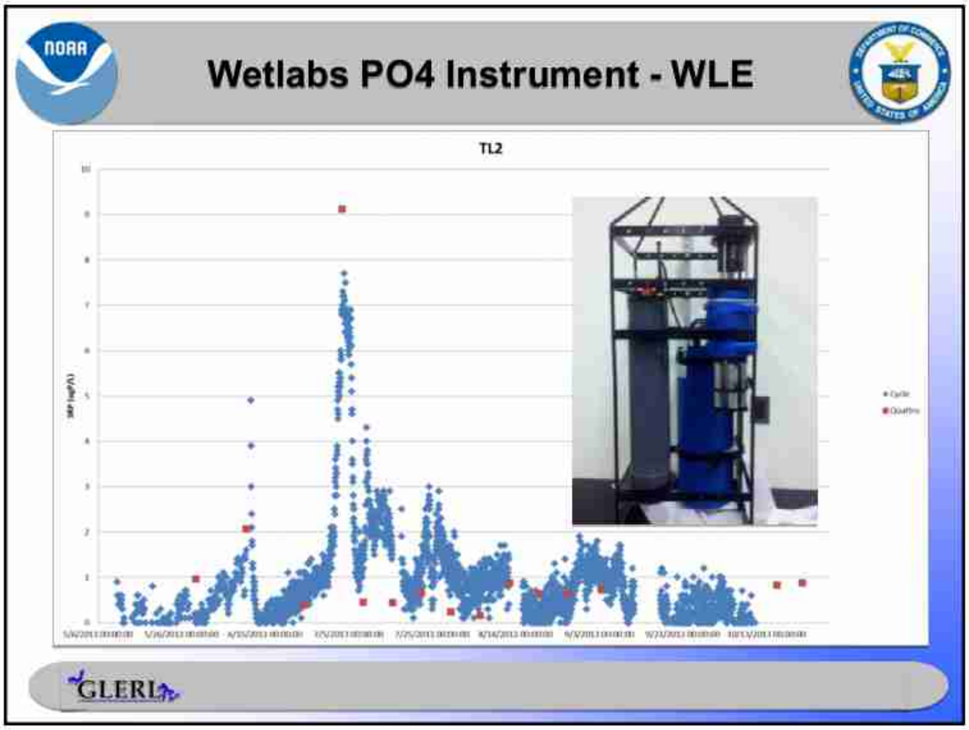
GLERL

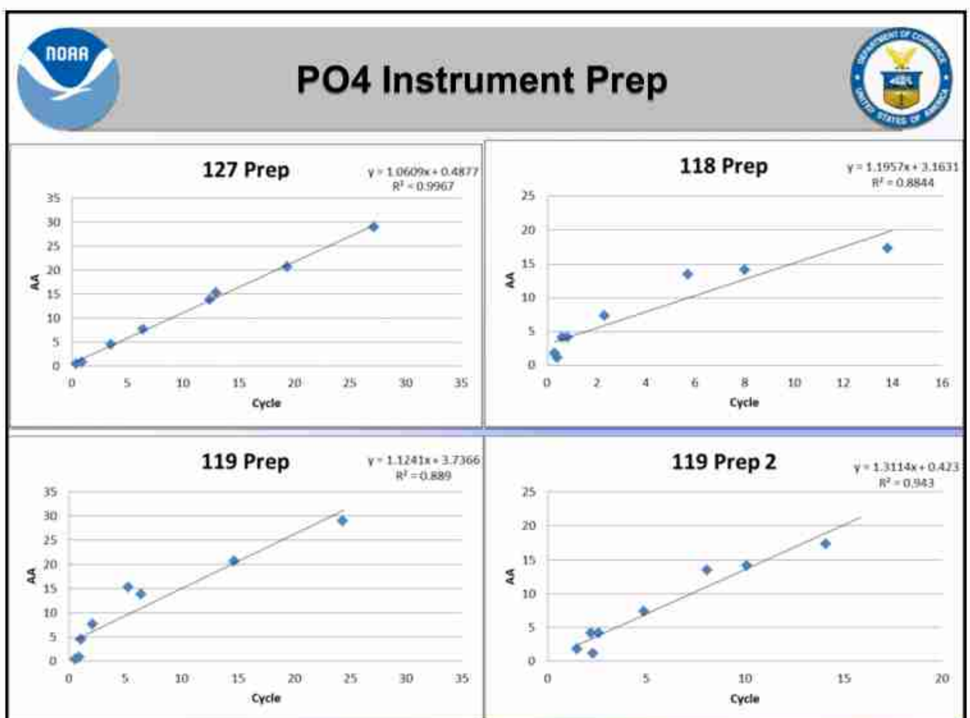
ReCON Network



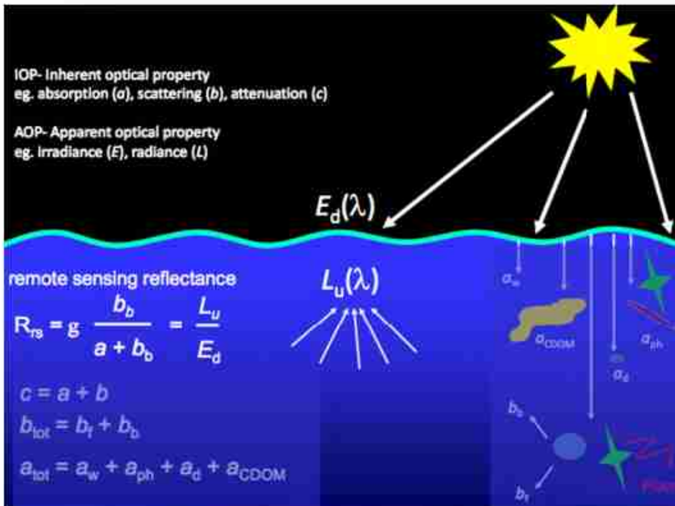

Ecological Observing System Development
GLERL


Ecological Observing System Development
Video Camera
Transducer
Rotator.
ReCON
Underwater Hub
BioSonics
Electronics


Wetlabs PO4 Instrument - WLE
TL2
GLERL


PO4 Instrument Prep
127 Prep
y = 1.0609x + 0.4877
R² = 0.9967
118 Prep
y = 1.1957x + 3.1631
R² = 0.8844
119 Prep
y = 1.1241x + 3.7366
R² = 0.889
119 Prep 2
y = 1.3114x + 0.423
R² = 0.943
AA
Cycle

Optical Properties Instruments



Wetlabs acs, bb9

Satlantic Hypergun

GLERL

GLOS/CILER AUV Glider

Green Bay Nearshore

Operation into ~2m depth shows substrate transition and macrophyte boundaries – classification requires additional PONAR/video sampling to match acoustic classes to bottom characteristics

CILER Glider

- 4 local missions
- 22 day Lake Michigan Deployment
  - 400km
  - ~1500 profiles
  - ~$150/day (Iridium +battery)
  - ~25km/day... Currents matter!
- CTD/Chl/CDOM/Backscatter
- ADCP


NOAA/GLERL Muskegon View 01 2013-Nov-27 08:00 EST
The End

Annis Water Resources Institute, AWRI-GVSU, Muskegon, MI - April 28, 29, 2014

Lake Michigan - Muskegon Lake Connectivity Workshop

George Leshkevich
NOAA/GLERL

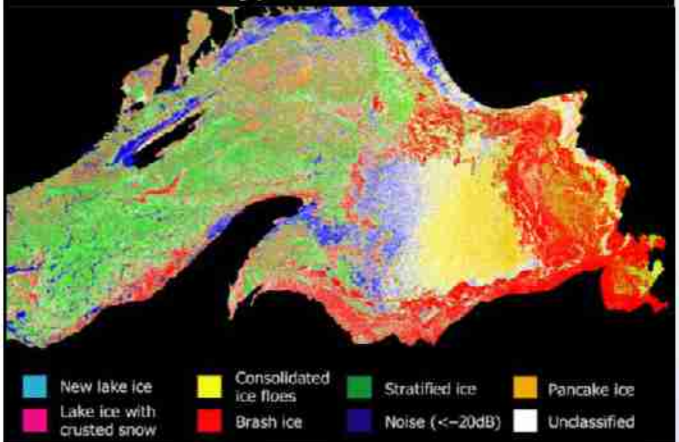
Current Research – George Leshkevich

- **Great Lakes SAR Ice Type Classification**
- NOAA/NESDIS, National Ice Center, U.S. Coast Guard, Shipping Industry, Public
- After finishing research and conducting demonstration for the USCG, NESDIS/NIC will create ice type classification charts operationally
- **Color Producing Agent (CPA) / HABs**
- NOAA/NESDIS, Great Lakes Managers, Modelers, Ecologists, Public
- NESDIS will create CPA products (chlorophyll, DOC, Suspended Minerals) operationally

2

Prototype Great Lakes Ice Classification Product

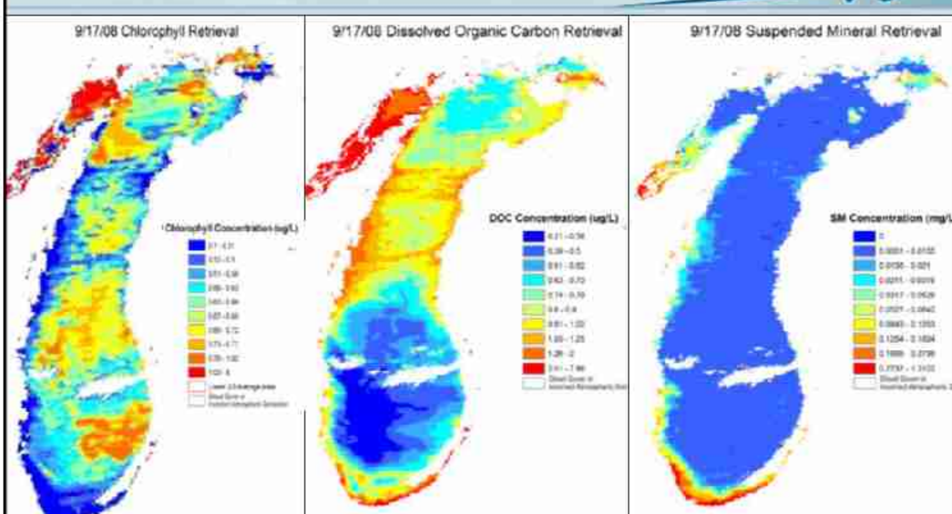
RADARSAT-1 SAR Image – Lake Superior Ice Type Classification



Description of work / interest:

Development of Great Lakes specific algorithms to create image products from existing and new satellite and airborne sensors

Color Producing Agent (CPA) Retrieval Algorithm Results – Lake Michigan



Average chlorophyll value for lower 2/3 of Lake Michigan: .62 µg/l

Current Research – George Leshkevich

- **Ice Thickness Measurement Using Ground Penetrating Radar (GPR)**
- U.S. Coast Guard, Canadian Coast Guard, National Ice Center, Shipping Industry, Modelers, Public
- Complete tests of GPR mounted on Coast Guard ice breaker after which the instrument and technology can be deployed operationally to measure transects of ice thickness

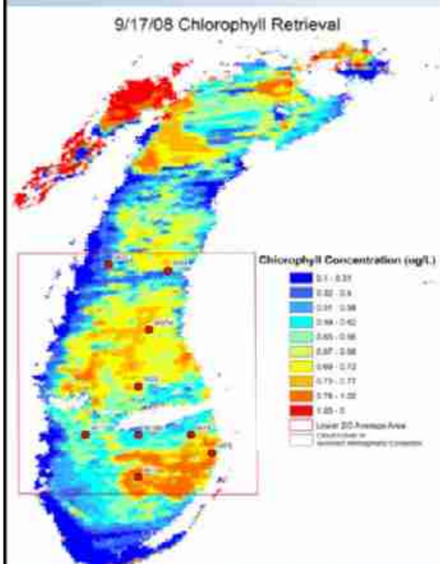
5

Future Directions – George Leshkevich

- Continue ice type classification algorithm research
- Continue GPR ice thickness research and testing
- Continue building CPA database and improve HAB and primary production algorithms
- 1)Evaluate/investigate satellite retrieval of soil moisture in the Great Lakes basin > could lead to a soil moisture product
- 2)Evaluate/investigate new and upcoming satellites for retrieval of ice thickness
- 3)Evaluate/investigate satellite hyperspectral data for better retrieval (spectral and spatial) of CPAs and HABs
- Collaborations: NASA JPL, MTRI, NASA GRC, NASA Goddard, NESDIS, NIC, U.S Coast Guard, Canadian Coast Guard
- Satellites/sensors: VIIRS, SMAP, Sentinel 1/3, SWOT, HICO

6

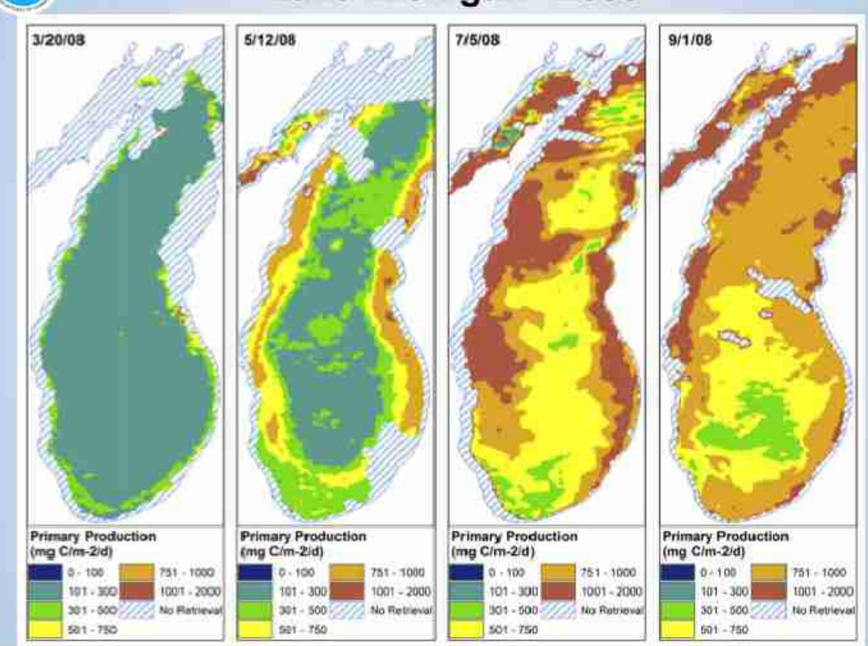
Chlorophyll Retrieval Compared to In-situ Measurements



EPA Station	EPA Value (µg/L)	Algorithm Retrieval 3km Buffer (µg/L)
MI11	0.46	0.72
MI17	0.62	0.61
MI18M	0.4	0.6
MI19	0.61	0.67
MI27M	0.52	0.72
MI32	0.96	0.62
MI34	0.72	0.6
MIFE	0.61	0.7
MI23	0.46	0.71
Average	**0.60**	**0.66**

	EPA Lower 2/3 Avg	Algorithm Lower 2/3 Avg
CHL µg/L	0.60	0.62

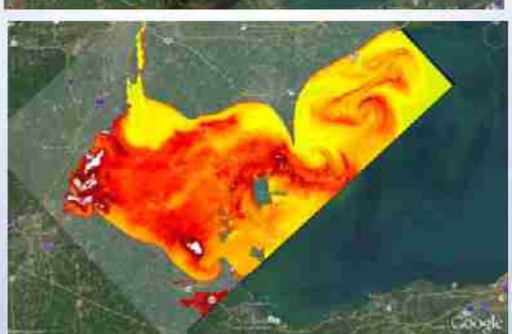
CPA Chlorophyll Retrieval Lake Michigan - 2008



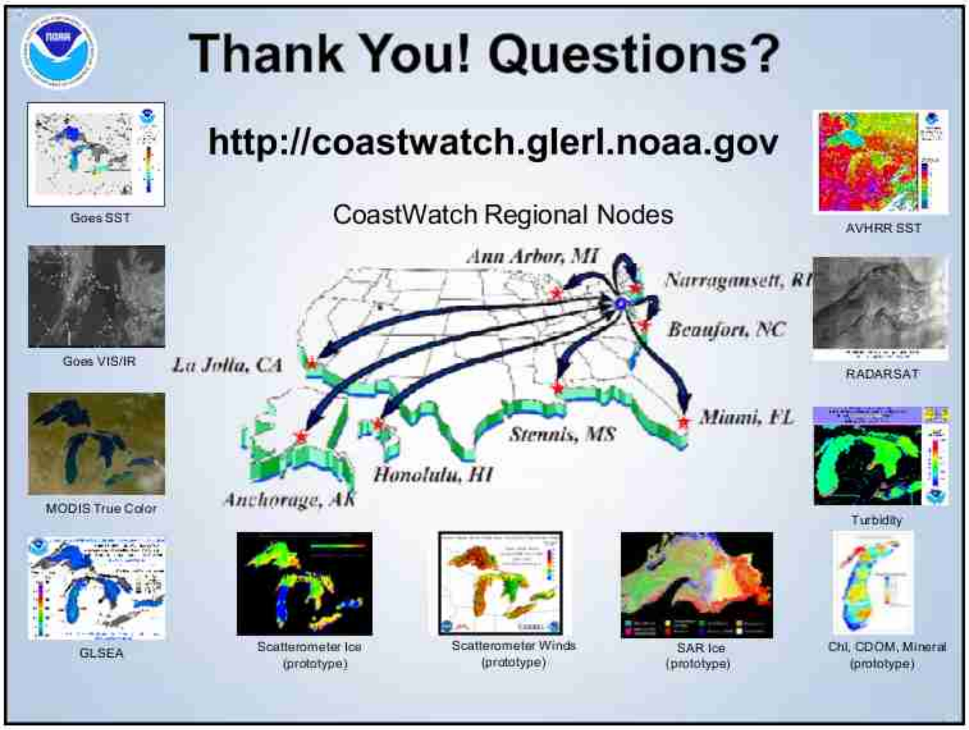
LANDSAT - 8 True Color April 9, 2014
30 meter resolution

9

HICO True Color Lake Erie Sept. 3, 2011
Hyperspectral 100 meter resolution



10


Thank You! Questions?
http://coastwatch.glerl.noaa.gov
CoastWatch Regional Nodes
Ann Arbor, MI
Narragansett, RI
Beaufort, NC
La Jolla, CA
Miami, FL
Stennis, MS
Honolulu, HI
Anchorage, AK
Goes SST
Goes VIS/IR
MODIS True Color
GLSEA
AVHRR SST
RADARSAT
Turbidity
Scatterometer Ice (prototype)
Scatterometer Winds (prototype)
SAR Ice (prototype)
Chl, CDOM, Mineral (prototype)

Muskegon Lake and Lake Michigan coastal observing plans

Annis Water Resources Institute

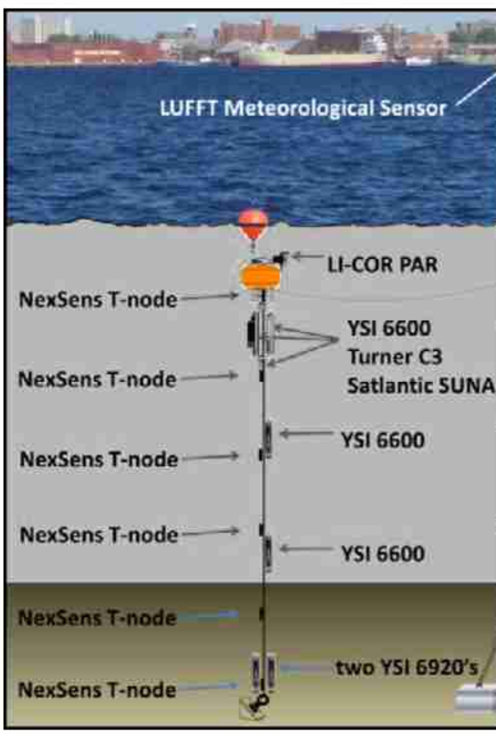
Grand Valley State University

Great Lakes Connectivity Workshop

April 28, 2014

NOAA – GVSU Observing System Collaborations

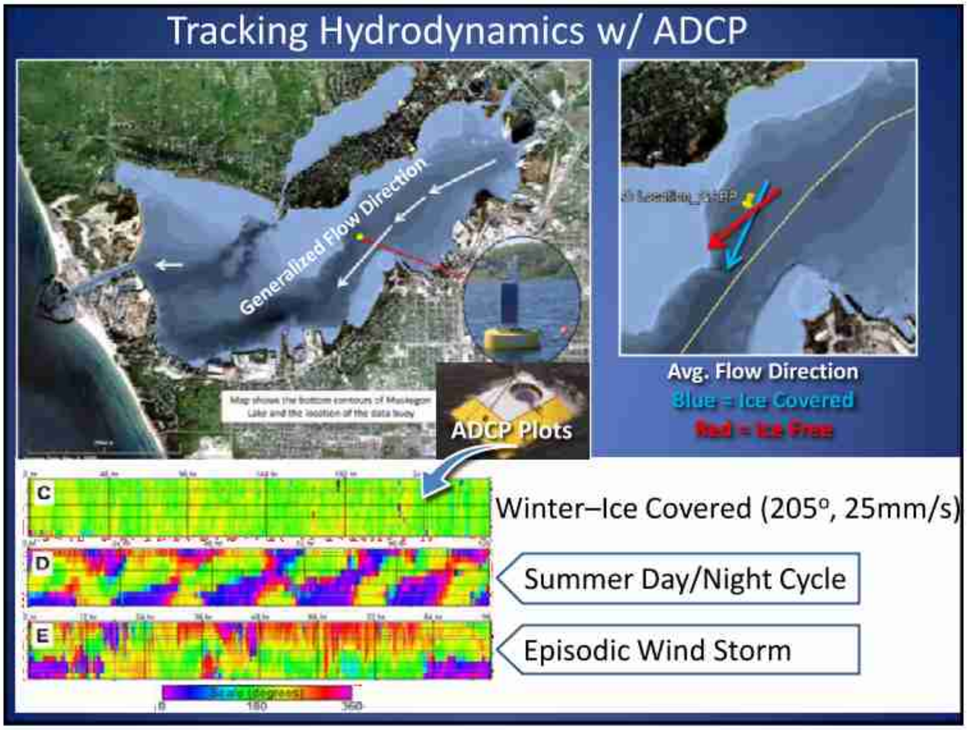
- Ship support - GVSU Muskegon Lake Buoy
- Guest sensor on M15 Buoy
- Lake Huron Sinkholes
- Ship support → proposals



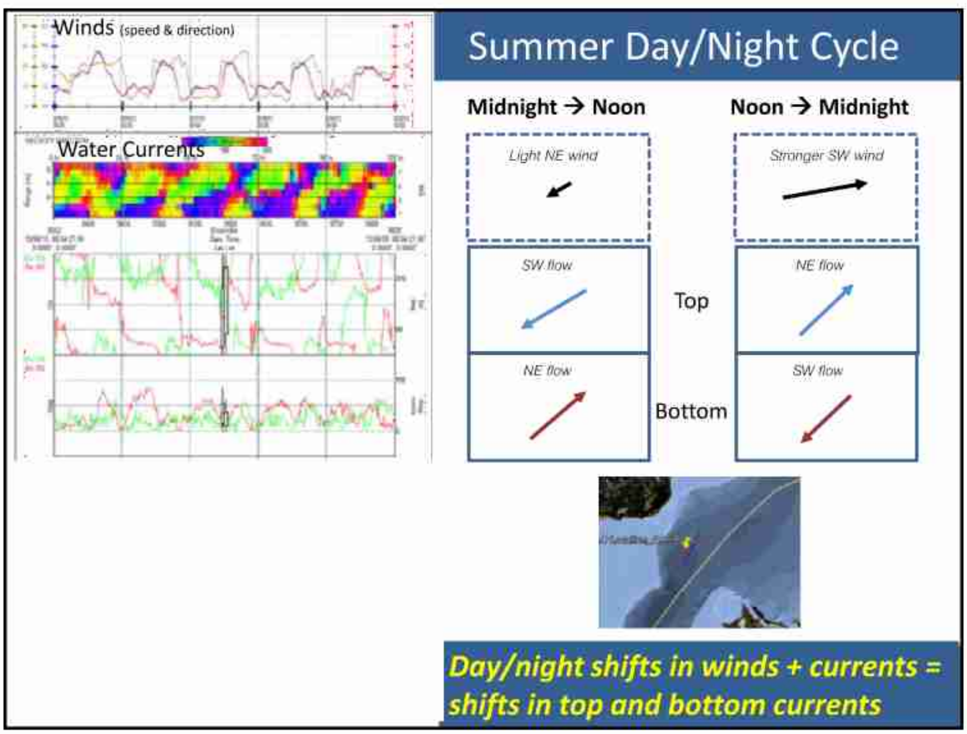
Water Depth (m)	T Nodes	Conductivity	pH	Turbidity	DO	CDOM	Nitrate	PAR	Chloro-phyll	Phyco-cyanin
1								x		
2	x x	x	x	x	x	x	x		x	x
5	x	x	x	x	x				x	
8	x x	x	x	x	x					
11	x	x	x	x	x					

Observation Focus Areas

- Support AOC delisting (water quality, chlorophyll, habitats)
- Algal/Cyanobacterial blooms
- Episodic events
- Hypolimnetic hypoxia
- Hydrodynamics
- P:R metabolism
- Nutrients



Tracking Hydrodynamics w/ ADCP
Generalized Flow Direction
Map shows the bottom contours of Muskegon Lake and the location of the data buoy
ADCP Plots
Avg. Flow Direction
Blue = Ice Covered
Red = Ice Free
C
D
E
Winter–Ice Covered (205°, 25mm/s)
Summer Day/Night Cycle
Episodic Wind Storm
0
180
360

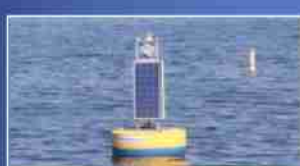


Winds (speed & direction)
Water Currents
Summer Day/Night Cycle
Midnight → Noon
Noon → Midnight
Light NE wind
Stronger SW wind
SW flow
NE flow
Top
NE flow
SW flow
Bottom
Day/night shifts in winds + currents = shifts in top and bottom currents

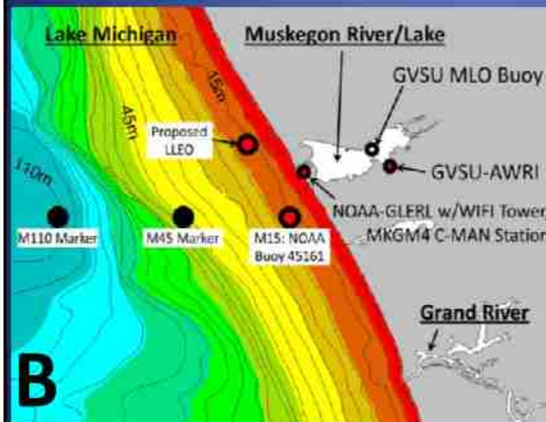
Boat-mounted ADCP
- *discharge, currents*

Where Do We Go From Here?

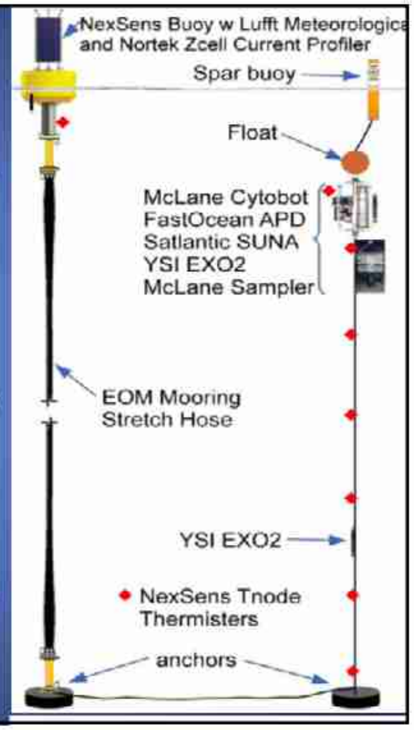
- **Explore cont. funding for Muskegon Lake Observatory**
- **Muskegon River → Muskegon Lake → Lake Michigan Nearshore**



Nearshore LM monitoring



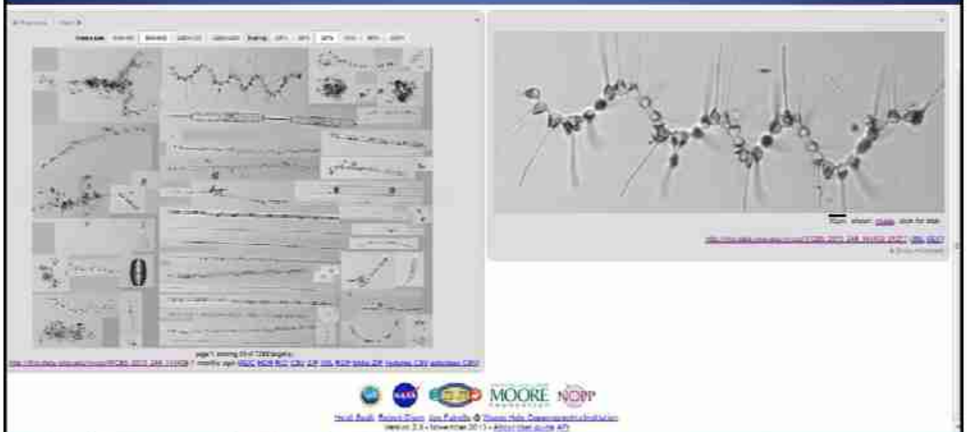
NSF-Major Research Instrumentation

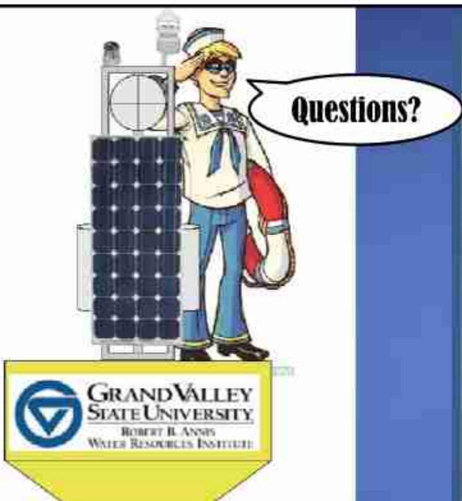


In Situ Imaging Flow Cytometer (Cytobot)

- Developed by WHOI (Olson and Sosik 2007); Available from McLane Research Labs
- Monitoring organisms (2-150 µm):
  - Photoautotrophs
  - Organisms that have consumed phototrophs
  - Other organisms/propagules
- HABs, food webs, invasives, waterborne pathogens
- Challenge: 37 watts
  - Buoy: 4x55Ahr batteries + 390W solar
  - → 1 hr sampling every 4 hours

WHOI MVCO 2006 - present



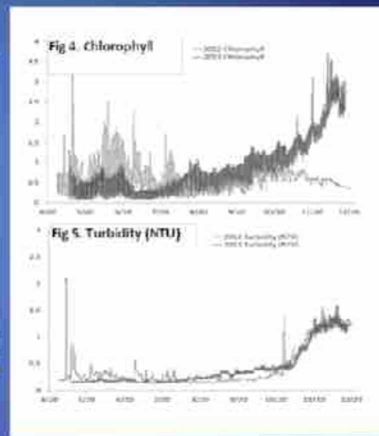


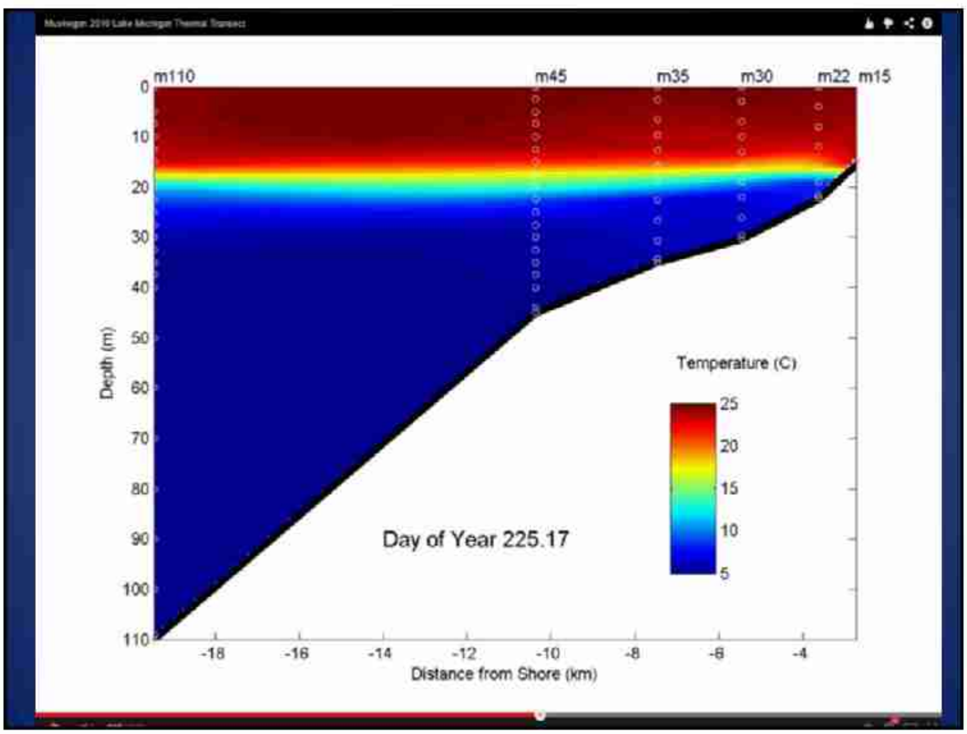
Great Lakes RESTORATION

GLERL
Great Lakes Environmental Research Laboratory

www.gvsu.edu/buoy

GVSU MAREC Windsentinel Buoy

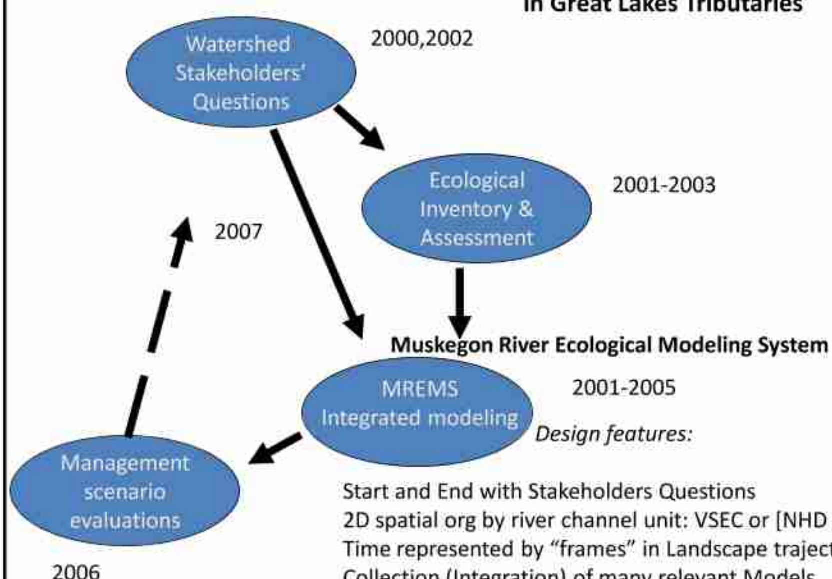




Forecasting the Future of the Muskegon River Estuary

Ed Rutherford
(for Mike Wiley)

Objective: Developing forecasting tools for Ecosystem Management in Great Lakes Tributaries



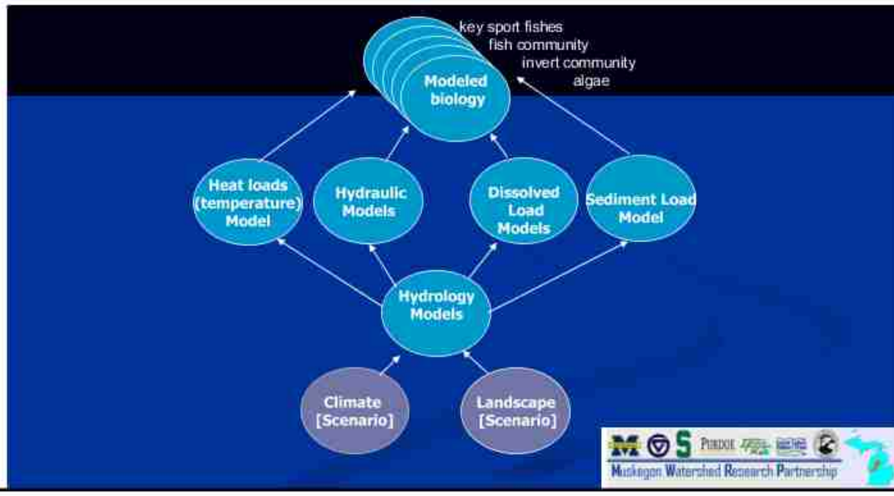
Design features:

Start and End with Stakeholders Questions
2D spatial org by river channel unit: VSEC or [NHD arcs]
Time represented by "frames" in Landscape trajectory
Collection (Integration) of many relevant Models
Variable time scales are OK

Ecological forecasting: multi-modeling the Muskegon

Library of mechanistic and empirical models provides a "bottom-up" framework for:

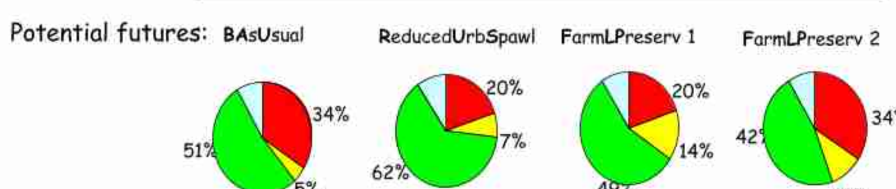
1. Exploring spatially explicit dynamics of climate, hydrology, landuse, and biological linkages
2. Clarifying "how the river works" and facilitating scenario gaming by stakeholders

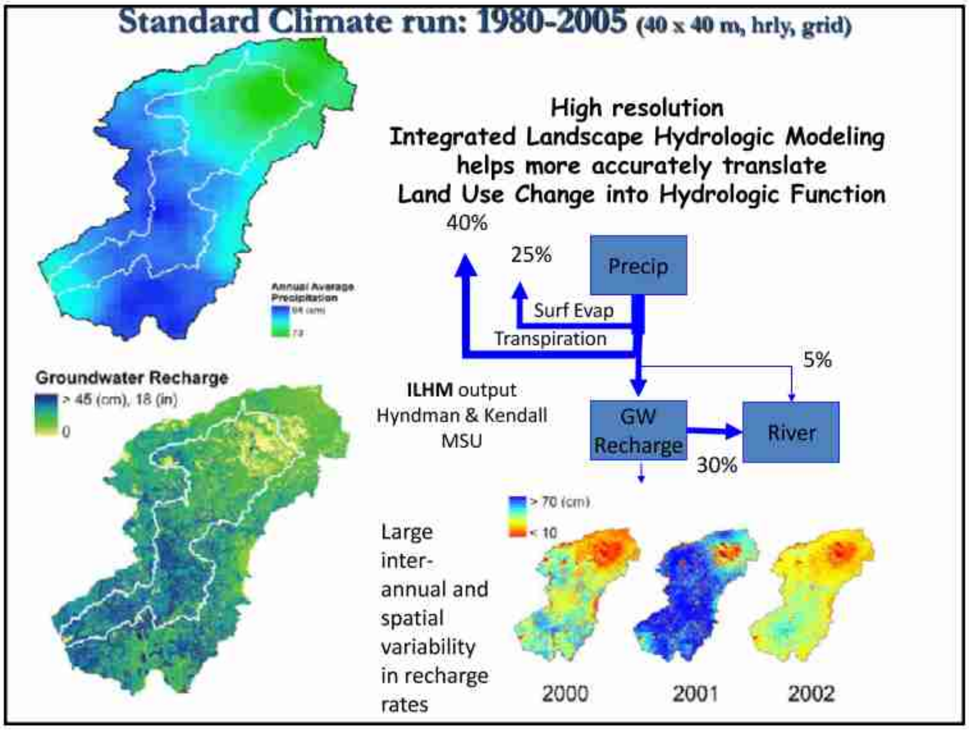


Key Watershed drivers: landuse and climate

Purdue's **LTM2**
a neural net model
generates management-sensitive
Land use forecasts and back-casts

Muskegon Stakeholders helped design alternate future landscapes scenarios by choosing different land use management options to evaluate (currently 12 scenarios)





Land Use Effects on Fisheries

Percent Change from 1998 Occurrence in Watershed

	Stt & Chinook	Stream Trout spp	Walleye	Smb and Pike
Best Case	+ 29	- 11	- 2	+ 1
Business As Usual	+ 27	- 12	- 46	+ 5
Worst Case	- 5	- 15	- 48	+ 4

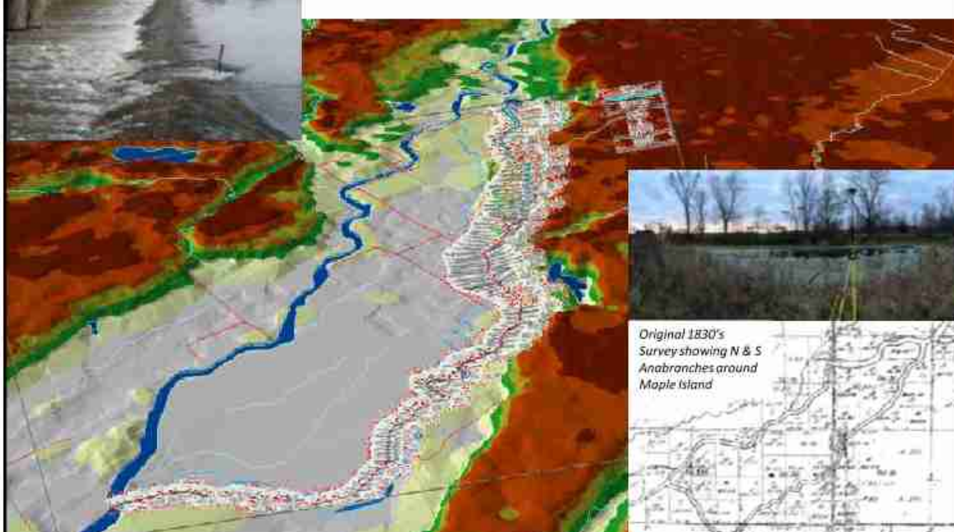
% Change in Species Occurrence in Muskegon Watershed With Summer Temperature Increase of +5 °F

	Winners	Losers
Steelhead		- 40%
Chinook salmon	No change	
Stream Trouts		- 45%
Smallmouth	+ 20%	
Northern Pike	+ 65%	
Walleye	No change	

Simulating reconnection of the Maple Island S. Anabranch (aka Maple River)

is there potential for:

decreased Mainstem flooding?
increased fish and wildlife habitat?



A flooded North Bayne Road near the corner of Maple Island Road due to flooding of the Muskegon River in Muskegon County's Cedar Creek Township on April 16, 2014. (M-Live)

Ecosystem Assessment and Database Framework

Ed Rutherford

(for Jan Stevenson and Catherine Riseng)

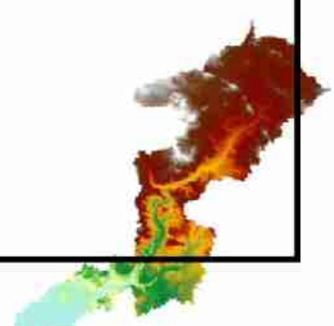
Muskegon Watershed Research Goals

Human Activities

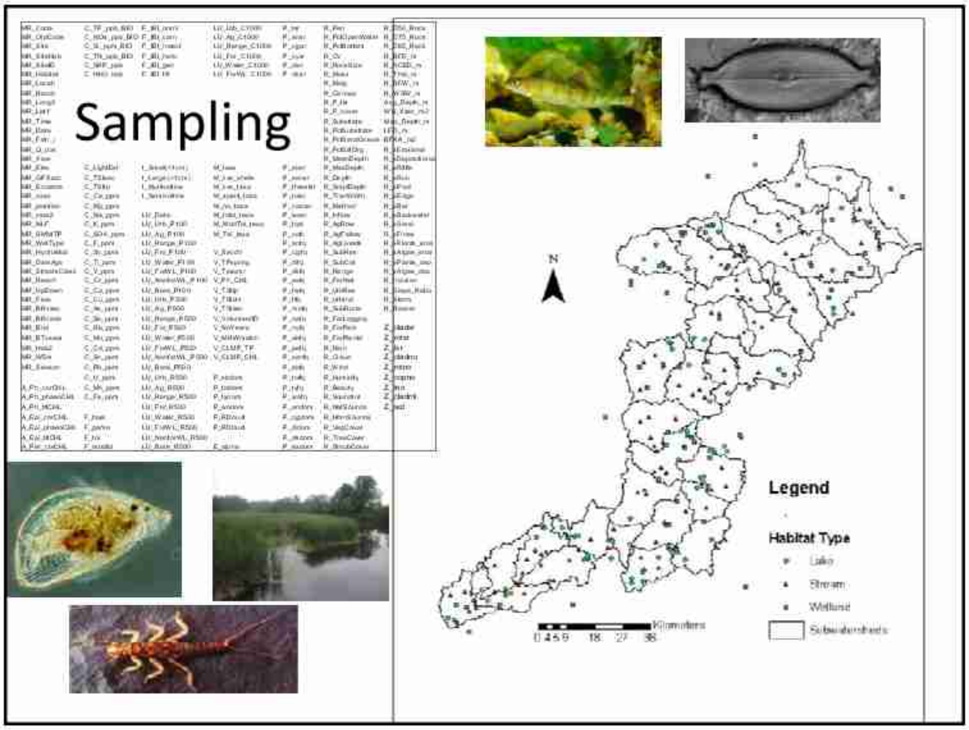
Contaminants & Habitat Alterations

Ecosystem Health Goods & Services

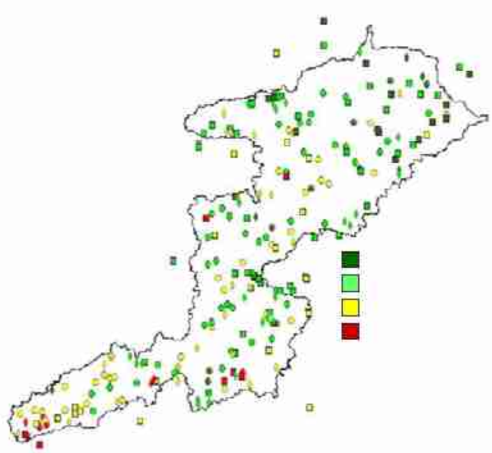
Quality of Life & Human Welfare

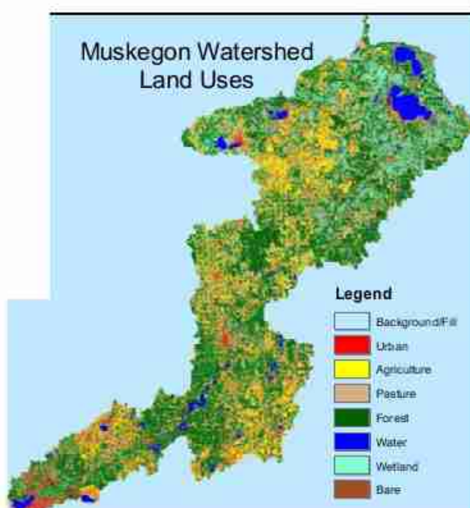


"Sustainable use of resources.....

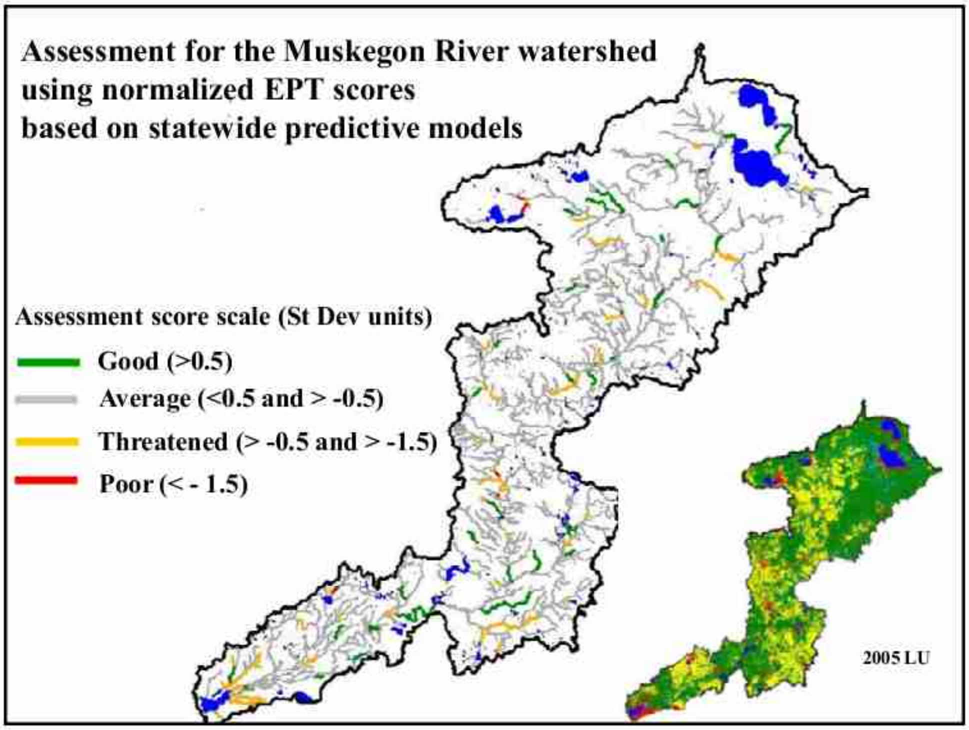


Ecological Condition is Related to Human Activities

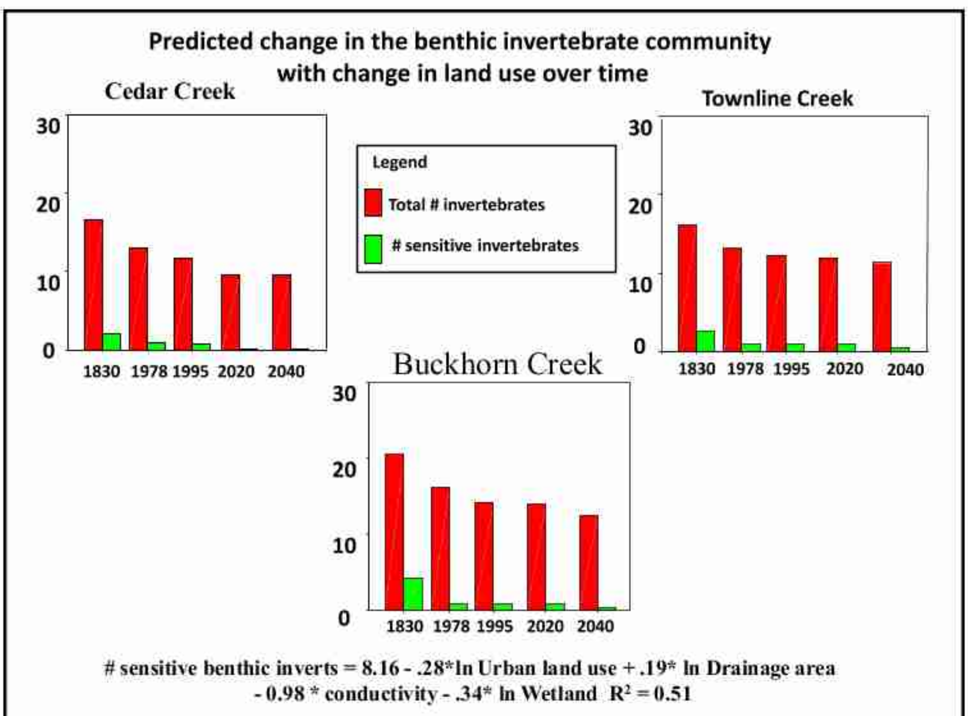




Habitat	Percentage by Class			
	Excel	Good	Fair	Poor
Streams	11	51	33	5
Lakes	6	52	33	9
Wetlands	28	48	22	2



Assessment for the Muskegon River watershed
using normalized EPT scores
based on statewide predictive models
Assessment score scale (St Dev units)
Good (>0.5)
Average (<0.5 and > -0.5)
Threatened (> -0.5 and > -1.5)
Poor (< - 1.5)
2005 LU



Predicted change in the benthic invertebrate community
with change in land use over time
Cedar Creek
Townline Creek
Buckhorn Creek
Legend
Total # invertebrates
sensitive invertebrates
30
20
10
0
1830 1978 1995 2020 2040
sensitive benthic inverts = 8.16 - .28*ln Urban land use + .19* ln Drainage area
- 0.98 * conductivity - .34* ln Wetland R² = 0.51

GLAHF

Great Lakes Aquatic Habitat Framework

Collaborative, Integrative, Bi-national Project

Funded by: Great Lakes Fishery Trust

University of Windsor

Environment Canada

Mid-Continent Ecology Division

DNR Michigan

NOAA

Michigan Tech Research Institute

Ontario

Michigan State University

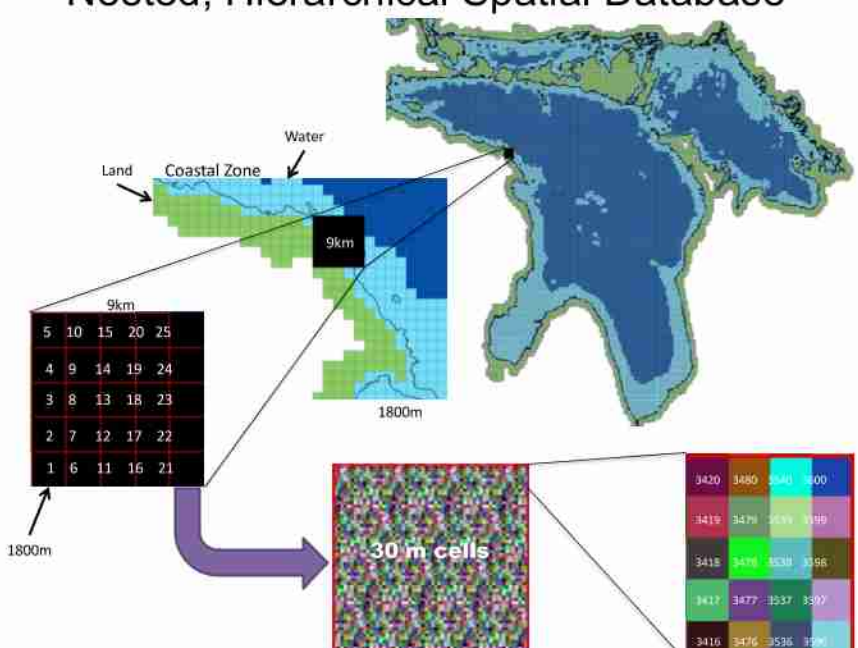
UMD Duluth Natural Resources Research Institute

The Nature Conservancy

USGS science for a changing world

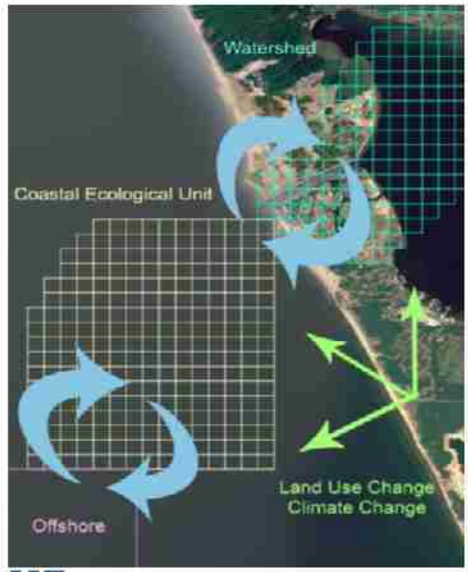
Natural Resources and Environment University of Michigan

Nested, Hierarchical Spatial Database

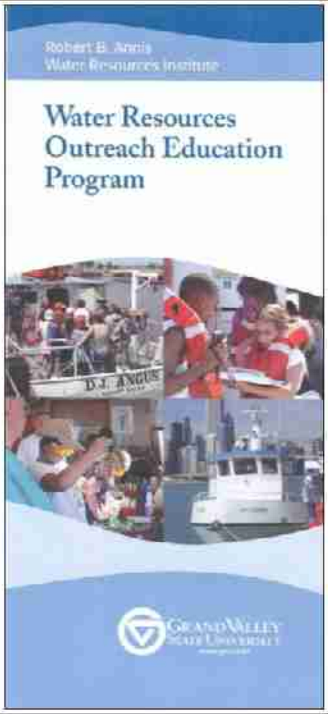


What Is GLAHF?

- Spatial framework: gridded network of cells with attributed habitat data
- Provides database structure to define ecological habitat units, support classification, and assessment
- Facilitates linking offshore, coastal and terrestrial process at multiple spatial and temporal scales



GLAHF



K-12 Education and Public Outreach

Janet Vail, Ph.D.
vailj@gvsu.edu

GRAND VALLEY STATE UNIVERSITY
ROBERT B. ANNIS
WATER RESOURCES INSTITUTE

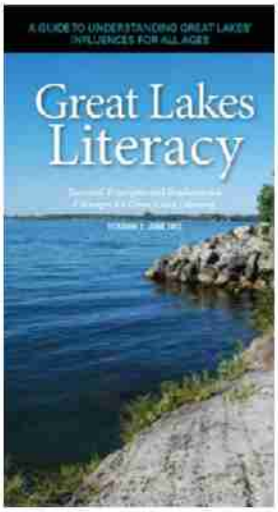
Specially designed vessels for research as well as education.

W.G. Jackson, 65 feet, 1996
Muskegon, MI

D.J. Angus, 45 feet, 1986
Grand Haven, MI

The Great Lakes Literacy Principles

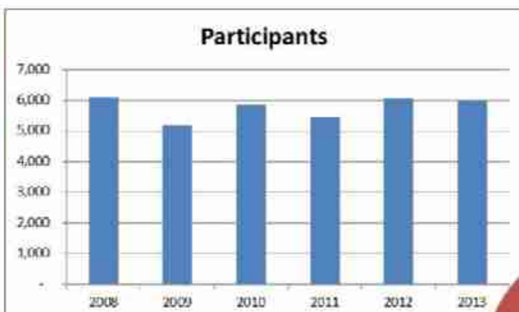
Vessel-based outreach helps spread the word

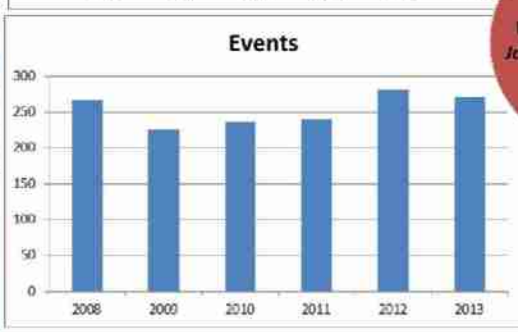


The Great Lakes Literacy effort had its origins in Ocean Literacy, a movement by hundreds of scientists and educators who contributed time and expertise to develop a concise framework for conveying the most important science principles and interconnected concepts that all citizens should know.

www.greatlakesliteracy.net

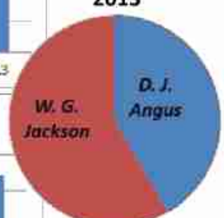
Water Resources Outreach & Education Program





Vessel program

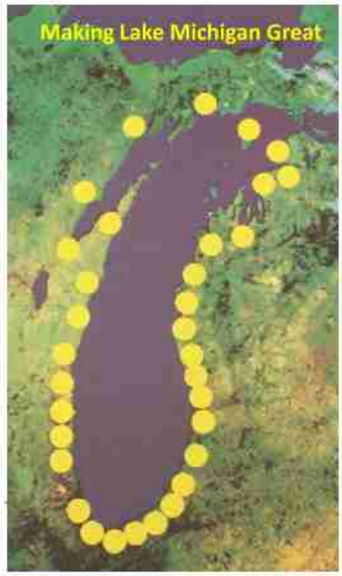
Participants 2013



Funding – Mainly Endowments

Public cruises funded by U.S. EPA

- 33 ports of call since 1998
- Support for the outreach effort of the Lake Michigan Lakewide Action & Management Plan
- Current grant: Great Lakes Restoration Initiative with Inland Seas Education Association and Michigan Sea Grant (MSU)



Great Lakes RESTORATION

Great Lakes RESTORATION

GLRI: Coordinated Onboard Education and Outreach Program

MSU Sea Grant Extension

- Focus Area: Lake St. Clair, lower Detroit River, Lake Erie
- Vessels: Clinton, Clinton Friendship (chartered)

Inland Seas Education Association

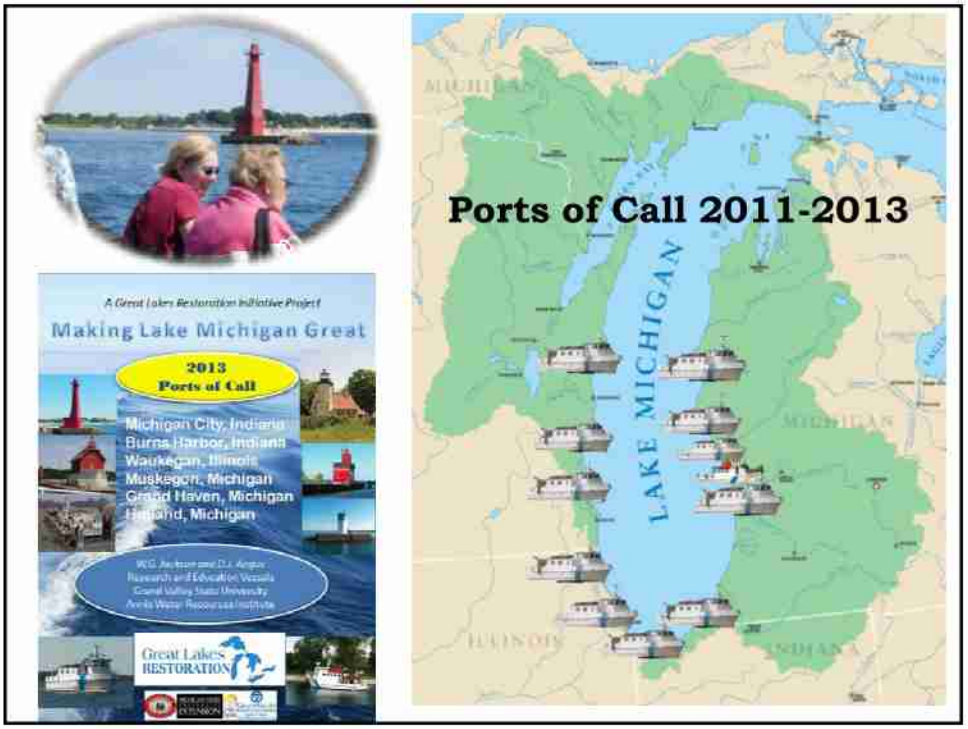
- Focus Area: Upper Lake Michigan, Northern Lake Huron
- Vessel: Inland Seas

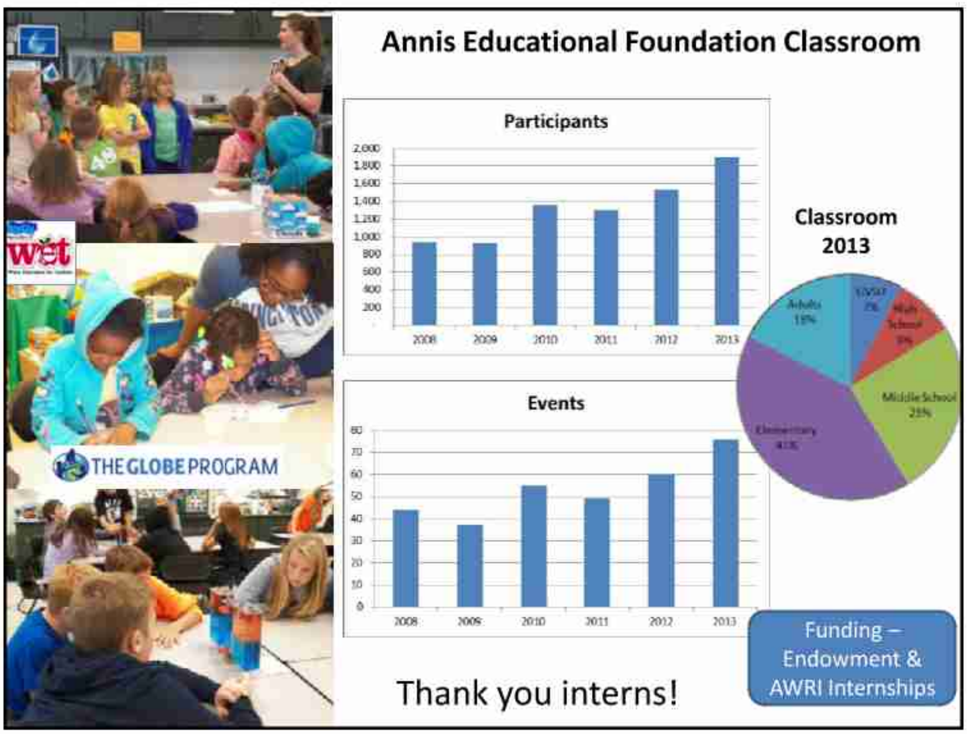
External Funding –
$291,721
$250,000

2 GLRI grants so far

GVSU Annis Water Resources Institute

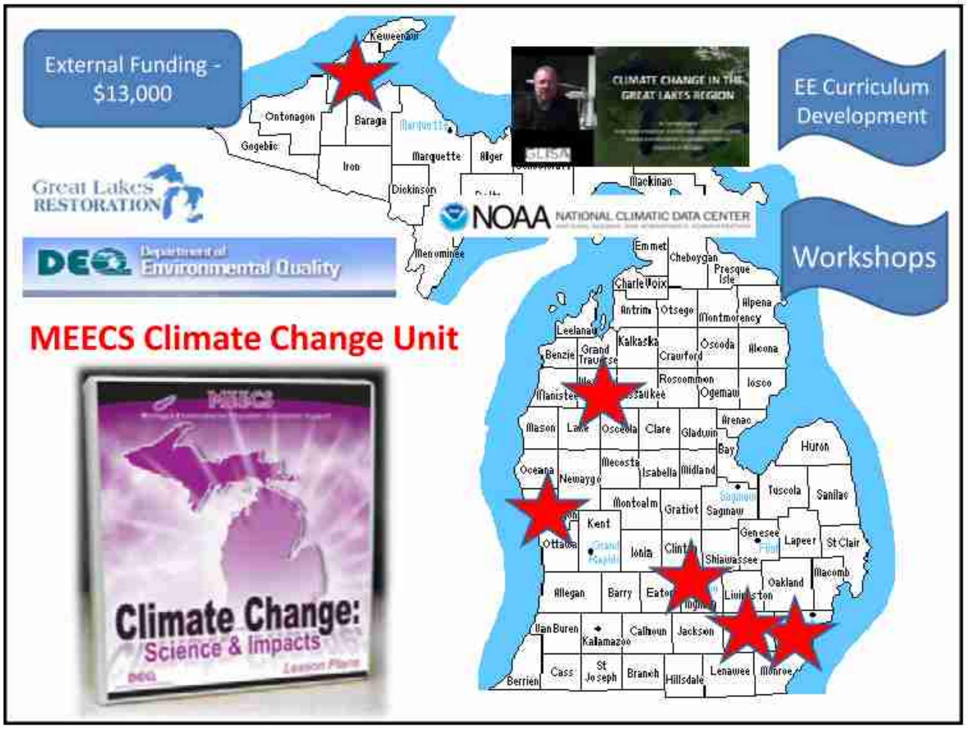
- Focus Area: Lower Lake Michigan
- Vessels: *W.G. Jackson, D.J. Angus*


Ports of Call 2011-2013
LAKE MICHIGAN
A Great Lakes Restoration Initiative Project
Making Lake Michigan Great
2013
Ports of Call
Michigan City, Indiana
Burns Harbor, Indiana
Waukegan, Illinois
Muskegon, Michigan
Grand Haven, Michigan
Holland, Michigan
W.G. Jackson and D.J. Angus
Research and Education Vessels
Grand Valley State University
Annis Water Resources Institute
Great Lakes
RESTORATION


Annis Educational Foundation Classroom
THE GLOBE PROGRAM
Participants
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
2008
2009
2010
2011
2012
2013
Events
80
70
60
50
40
30
20
10
0
2008
2009
2010
2011
2012
2013
Classroom
2013
Adults
15%
Middle School
25%
Elementary
41%
Funding –
Endowment &
AWRI Internships
Thank you interns!


Groundswell
What We Do
Schools
Partners
Resources
Events
News
Groundswell Community Partners
Workshops & Conferences
LAKE MICHIGAN
STATE OF THE LAKE
Bay Watershed Education and Training (B-WET)
NOAA OFFICE OF EDUCATION
West Michigan Great Lakes Stewardship Initiative
West Michigan Great Lakes Stewardship Initiative
Great Lakes Earth Partnership
RESTORE Institute
Great Lakes RESTORATION
Ecological Restoration from the Schoolyard to the Great Lakes


External Funding - $5,000/year
Workshops
Facilitators
Water Festivals
MICHIGAN
PROJECT
WET
Water Education for Teachers
Off-site Events
Educators
Project WET
AWRI is the State of Michigan Coordinator



Summary

- Trips for students Grade 4 and up
- *Making Lake Michigan Great* for U.S. EPA
- Classroom activities and building tours
- Conferences
- Teacher workshops
- Curriculum development
- Collaboration Ideas: Great Lakes Literacy principles, public outreach, teacher workshops

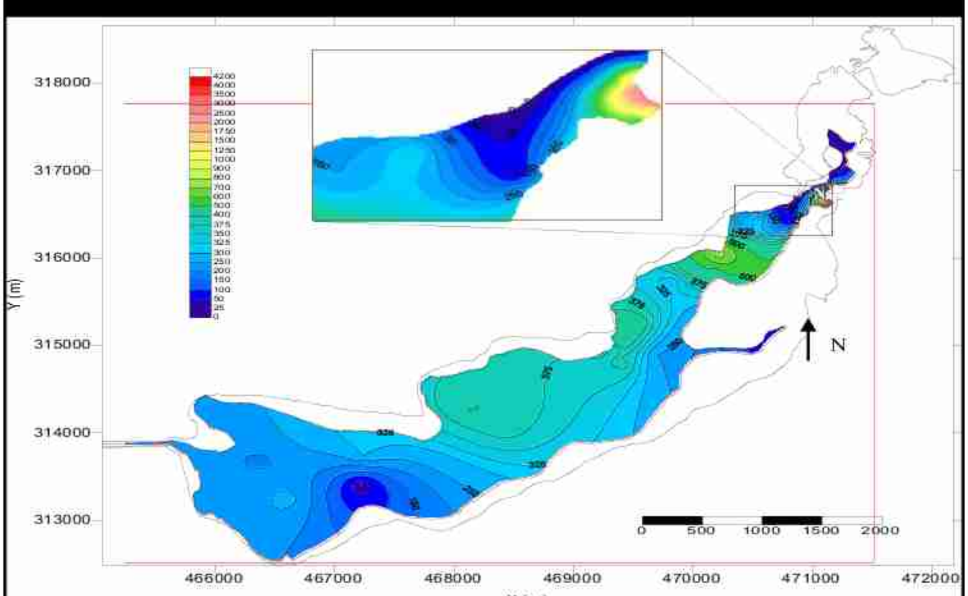
BUIs for White Lake

Impairment	Rationale
Restrictions on fish and wildlife consumption	Elevated PCBs in carp and mercury in walleye and bass
Eutrophication and Undesirable Algae	Historic eutrophic conditions from wastewater discharges
Degradation of Benthos	Low diversity, low numbers, dominance by worms, anoxia, and contaminated sediments from tannery and specialty chemical wastes

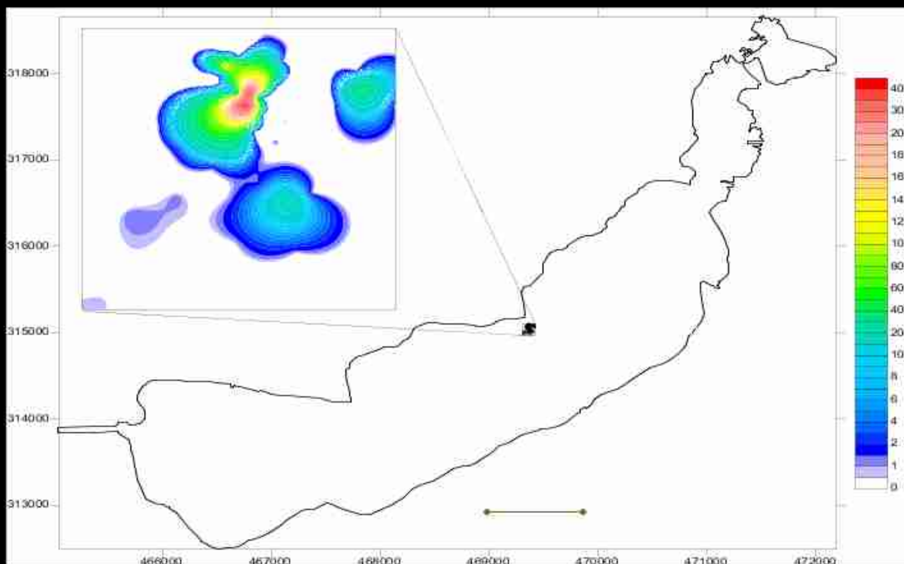
Questions

- What is the nature and extent of contamination?
- What and where are the specific impairments?
- What needs to be done before restoration can begin?
- What are the restoration targets?
- Has the AOC achieved the restoration targets?

Chromium Distribution in White Lake Sediments



Distribution of PCBs in White Lake (GVSU and Earth Tech 1998-2001 data)



Tannery Bay
Remediation 80,000 yds^3 2002/2003

Hooker/Occidental Chemical Remediation 15,000 yds^3 2002

Target Setting Process 2005

1. Prioritize a list of BUIs for target setting
2. Consider historical and current sources of degradation
3. Identify indicator parameters/target levels from site specific information, regulatory guidelines, and literature references
4. Preliminary approval from the PAC and stakeholders
5. Scientific/agency peer review
6. WLPAC wanted more restrictive targets than DEQ criteria
7. Final target approval in 2009

Summary of Benthic Invertebrate Target Status

Summary of Aquatic Macroinvertebrate Results for White Lake					
	Target	2001	2009	2010	2011
Shannon Weaver	1.50	1.38	1.48*	na	na
Amphipod Survival	> 60%	11/15	4/4	na	na
% Oligochaeta	<75	65	59	na	na
# Chironomidae #/m²	>500	649	729	na	na
# Hexagenia #/m²	Increasing Trend	62	120	145	178
# Amphipods #/m²	Increasing Trend	1010	2508	3612	3890

Fish Consumption BUI

- Key fish species: largemouth bass, and carp
- Sample design: 10-20 fish of each species collected in July-September
- Tissue analyzed: edible portion
- Reference system: Pentwater Lake
- The results of the 2006 and 2011 fish sampling found no statistical difference between the AOC and the reference system.

Eutrophication and Undesirable Algae

Station	Summer July 19, 2011			Fall October 24, 2011		
	TP (µg/l)	Chlor a (µg/l)	Secchi Disc (m)	TP (µg/l)	Chlor a (µg/l)	Secchi Disc (m)
1	27	7.8	1.8	23	5.5	2.2
2	25	7.2	2.2	22	5.8	2.5
3	21	7.0	2.1	20	4.3	2.1
Mean	24	7.3	2.0	22	5.2	2.3
Target	30	< 10	≥ 2	30	< 10	≥ 2
2005 Mean	28	8	1.8	20	7	2.2
1972 Mean	45	18	0.9	-	-	-
TSI Index	50	50	50	50	47	48

Current Status

- The delisting of all three BUIs was approved by DEQ and EPA in 2012
- Delisting of remaining BUIs in 2014
- Removal of the White Lake AOC from the list anticipated n 2014

Important Considerations

- There always will be unanticipated problems, glitches, delays, or mistakes. That's why it's so important to remain flexible, be willing to take on different roles, and work with project partners to resolve problems on short notice.
- Quality scientific assessments, specific metrics, and collaborative communication have been vital to achieving the successes in the White Lake AOC.

Muskegon Lake

- Benthos – Bear Lake, Ryerson Creek Mouth, Tributaries
- Eutrophication – Bear Lake
- Fish Consumption - Done